AN ASSESSMENT OF THE TREES OF THE GREENING SOWETO TREE PLANTING PROJECT IN JOHANNESBURG, SOUTH AFRICA

by

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ABSTRACT

The Greening Soweto Tree Planting project in the City of Johannesburg, South Africa, was a greening initiative aimed at ensuring that benefits of the 2010 FIFA World Cup, presented that year in the country, extended beyond the event. In assessing the trees of this project, it was confirmed that the target number of trees consisting mainly of indigenous tree species were planted predominantly as street and park trees in previously disadvantaged areas, traditionally known to have the least trees in the city. The survival rate of the project is estimated to be 43.46%, implying inadequacies in tree planting and management of the project and necessitating guidelines with recommendations to improve tree planting practices in the city. Growth relationship equations for *Olea europaea* subsp*. africana* and *Searsia lancea* were developed and the growth parameter analysis reveals that all trees grow better in parks but *C. africana* trees should rather be planted on sidewalks than on medians, *S. lancea* trees should preferably be planted on medians and *C. erythrophyllum* may be planted on sidewalks or medians as they would grow well in both locations. It is estimated that this project contributed 30 390.11 tCO_2 of standing carbon stocks valued at R3 646 812,87 or US$303,901.07 (assuming a CO_2 price of US$10.00) in 2017 and could potentially contribute 387 170.93 tCO_2 of sequestered carbon stocks valued at R46 460 511,82 or US$3,871,709.32 by 2031 as mitigation action against climate change. A positive connection impacting the growth of the trees has been identified between land use, land cover and maintenance, indicating that the best locations for trees are maintained parks and formal residential areas as well as paved areas where irrigation is provided. The presence of pests and diseases, conflict with overhead structures and roads and a lack of pruning negatively impacted the growth of the trees. Guidelines for new tree planting projects have been developed with recommendations to maintain the canopy cover percentage in the established urban forest, enhance tree planting in the previously disadvantaged regions, improve the survival rate of new tree planting projects and establish community engagement forums to inform future tree planting of the city.

Keywords: tree planting, allometry, carbon sequestration, growth rate, land use, land cover, tree maintenance, tree planting guidelines

DECLARATION

I, EM van Staden (46217274), hereby declare that the thesis, with the title:

AN ASSESSMENT OF THE TREES OF THE GREENING SOWETO TREE PLANTING PROJECT IN JOHANNESBURG, SOUTH AFRICA

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ABBREVIATIONS/ACRONYMS

AFFA	*Afrocarpus falcatus*
AGC	Above ground carbon
ANOVA	One-way analysis of variance
CAES	College of Agriculture and Environmental Sciences
CAVAT	Capital Asset Value for Amenity Trees
CBD	Central business district
CBH	Circumference at breast height
CDM	Clean development mechanism
CEAF	*Celtis africana*
CGL	Circumference at ground level
CL	Confidence level
CTLA	Council of Tree and Landscape Appraisers
COER	*Combretum erythrophyllum*
CoJ	City of Johannesburg
CO_2	Carbon dioxide
CO_2e	Carbon tax equivalent
COP	Conference of the Parties
DAH	Diameter above ankle height
DBH	Diameter at breast height
DGL	Diameter at ground level
DMRT	Duncan multiple range test
EIA	Environmental impact assessment
Eq	Equation
FIFA	Fédération Internationale de Football Association
FTFA	Food and Trees for Africa
GHG	Greenhouse gas
GIS	Geographic information systems
GPS	Global positioning system
GSTP	Greening Soweto Tree Planting project
HACA	*Harpephyllum caffrum*
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated pest management
ISA	International Society of Arboriculture
ISO	International Organization for Standardization
IVI	Importance value index

JCPZ	Johannesburg City Parks and Zoo
KIAF	*Kiggelaria africana*
LA	Los Angeles
LIDAR	Light detection and ranging
m	Metre
m^3	Cubic metre
mm	millimetre
MRV	Measurement, reporting and verification
NASA	National Aeronautics and Space Administration
NYC	New York City
OLEU	*Olea europaea subsp. africana*
POSP	*Podocarpus* spp.
QTRA	Quantified tree risk assessment
R	Rand (South African rand)
RC	Root carbon
RDM	Root dry biomass/root dry matter
REDD	Reducing emissions from deforestation and forest degradation
RHO	Spearman's rank correlation coefficient
RUSI	Rapid urban site index
SANS	South African National Standard
SATAM	South African tree appraisal method
SCBR	*Schotia brachypetala*
SCS	Standing carbon stocks
SE	Standard error percentage
SELA	*Searsia lancea*
SEGA	*Senegalia galpinii*
SEPE	*Searsia pendulina*
SQRT	Square root
STEM	Standard Tree Evaluation Method
STRATUM	Street Tree Assessment Tool for Urban Forest Managers
TC	Total carbon
tCO_2	Weight of carbon dioxide in tons
TDM	Total above ground biomass/total dry matter
UFORE	Urban forest effects model
UFMPs	Urban forestry management plans
UNFCCC	United Nations Framework Convention on Climate Change

UNISA	University of South Africa
US	United States
USA	United States of America
US$	United States dollar
USDA	United States Department of Agriculture
VAKA	*Vachellia karroo*
VASI	*Vachellia sieberiana var. woodii*
VHR	Very high-resolution images
VolCalc	Tree volume calculation software
ZAR	South African rand

CHAPTER 1

INTRODUCTION

More than two-thirds (66.37%) of South Africa's total population lived in urban areas and cities in 2018 compared to 61.15% in 2008, indicating continued growth. Approximately 50% of the population resides in the 10 largest cities, of which Johannesburg is the largest in South Africa with the highest population of nearly 5 million people (4 949 347) (Statistica, 2020). It is estimated that by 2050, 80% of South Africans will be living in urban areas, increasing the demand on basic infrastructure requirements. The challenges of urbanisation range from unemployment and urban poverty to environmental consequences and spatial challenges perpetuated by the apartheid spatial patterns, such as continued segregated urban settlements, access to services and unsustainable infrastructure networks (Parliamentary Monitoring Group, 2019). Environmental problems caused by urbanisation are air and water pollution, increased flooding caused by a lack of permeable surfaces and soil erosion (Kuchelmeister, 1999). These and the lack of local authorities to provide solutions (Mohai, Pellow & Roberts, 2009) contribute to a disproportionate burden of environmental pollution found in poorer communities (Newel, 2006) and lead to environmental injustice, exacerbated by the apartheid regime of the previous government (McDonald, 2002). Management and maintenance of urban developments, which include the provision of basic services and urban greening (including urban forestry), are functions of municipal or local governments (Chishaleshale, Shackleton, Gambiza & Gumbo, 2015; Gardner, 2018). In the City of Johannesburg (CoJ), the management of the urban forest is the responsibility of the Johannesburg City Parks and Zoo (JCPZ), a division of the local government.

The CoJ has a responsibility to demonstrate environmental justice by rectifying the wrongs of the past but also avoiding them in future. In short, McDonald (2002) defines environmental justice as “social transformation directed towards meeting basic human needs and enhancing our quality of life” and challenges the abuse of power resulting in disadvantaged people having to suffer the effects of environmental damage caused by disregard of others. The mayor of the city initiated a tree planting project in 2006, planting trees and developing parks to transform the dusty streets in the south-western regions of the city and eliminating the “green divide” – a legacy of apartheid. Dusty streets refer to the condition of the environment in Soweto caused by the surrounding gold mine dump dust prevalent during windy days (Buff, 2017). The aim of planting trees in a city is not only to create sustainable and habitable urban environments but also to ameliorate the effect of greenhouse gases and climate change (Nowak & Crane, 2002).

Therefore, the aim of the study was to investigate the Greening Soweto Tree Planting (GSTP) project, determining the location of the trees, assessing the existing trees, determining the carbon value of the trees as well as the impact of land use, land cover and external site factors on the growth of the trees. The final aim of the study was to compile guidelines for new tree planting projects to improve the growth and survival rates of the trees in these projects in the city.

1.1 Background

1.1.1 The urban forest and climate change

Urban forests provide multiple ecological services that mitigate environmental concerns such as air pollution, stormwater flooding and energy conservation. Urban forests also have significant potential to mitigate the effects of global warming and climate change by sequestering atmospheric carbon dioxide (McPherson, Simpson, Peper, Maco & Xiao, 2005; Tyrväinen, Pauleit, Seeland & De Vries, 2005). Trees sequester carbon by fixing the carbon during the process of photosynthesis and storing excess carbon as woody biomass as they grow. The carbon sinks offset greenhouse gas (GHG) and carbon dioxide emissions (Nowak & Crane, 2002; Nowak, Greenfield, Hoehn & Lapoint, 2013). The monetary value of carbon sequestration benefits can be determined by estimating total biomass and applying allometric equations. Researchers have estimated that urban trees in the US store approximately 23 million tons of carbon per year valued at $460 million per annum (Nowak & Crane, 2002). Therefore, cities worldwide are motivated to expand their urban forests by planting more trees and initiating tree planting projects (McPherson & Young, 2010), often establishing ambitious initiatives to plant a million or more trees (Young, 2011). These large-scale projects are found mainly in developed countries, but developing countries such as Brazil, India and some sub-Saharan African countries are embarking on similar projects (Yao, Konijnendijk van den Bosch, Yang, Devisscher, Wirtz, Jia, Duan & Ma, 2019).

1.1.2 Tree planting projects

Successful tree planting projects are dependent on carefully planned tree planting policies, strategies and guidelines containing goals and aims to guide long-term tree planting in a city (Booth, 2006). Challenges in the implementation and management of urban tree planting projects include selecting the most suitable tree species and planting location based on factors such as species diversity, maintenance requirements, climatic conditions, soil quality, the physical environment, land ownership and relevant legal aspects (Clark & Kjelgren, 1989; Pauleit, 2003). The success of tree planting projects is also dependent on maintenance practices to keep mortality rates low, ensure high survival rates and increase the extent of the benefits provided by the trees (Vogt, Hauer & Fischer, 2015).

Establishing tree planting programmes that will withstand the test of time is a challenge. Political agendas and pressures, partners and the public who support the initiatives, coupled with limited resources, often negatively affect tree planting programmes and their sustainability. These concerns highlight the importance of appropriate guidance to ensure successful implementation and management (McPherson & Young, 2010). A strategic tree planting plan provides commitment and strategic direction for tree planting and management in an urban environment and consists of guidelines for propagation, planting, replacing, pruning and removing of trees, as well as general maintenance and management of trees (Kenney, Van Wassenaer & Satel, 2011; Gibbons, 2014; Salbitano, Borelli, Conigliaro & Chen, 2016).

1.1.3 Greening Soweto

The GSTP project, also referred to as the Greening Soweto Legacy Project, was launched in the CoJ by Mayor Amos Masondo in 2006 with the planting of 6 000 trees in 10 minutes. The target to plant 200 000 trees was reached in 2010, just before the start of the FIFA 2010 World Cup, presented that year in South Africa. The aim of the project was to transform dusty streets, barren wastelands and landfill sites in Soweto into winning parks, to provide eco-services and eliminate the "green divide" – a legacy of inequality separating the wealthy north from the poorer south-western regions in the city. The project included developing regional parks and outdoor recreational facilities, beautifying medians and planting street trees. This greening initiative became one of the mayor's legacy projects with the aim of ensuring that the benefits of the 2010 FIFA World Cup extended beyond the event (Johannesburg City Parks and Zoo (JCPZ), 2012). On 8 November 2010, Johannesburg City Parks, now Johannesburg City Parks and Zoo, won a gold Liveable Communities Award for this project, at the UN-endorsed Liveable Communities (LivCom) Awards in Chicago, United States. The project focused on balancing the distribution of the urban forest throughout the entire city (JCPZ, 2010).

1.1.4 City of Johannesburg's urban forest

Johannesburg was founded on the discovery of substantial gold reserves in 1886 (Beavon, 2004), and formally recognised as a city by the Zuid Afrikaansche Republiek Volksraad in 1897 in an area that was originally grassland called the Highveld, with trees found only along riparian zones next to small rivers (Turton, Schultz, Buckle, Kgomongoe, Malungani & Dracker, 2006). Under apartheid, the city was separated by the central business district (CBD) into the affluent white suburbs to the north (Regions A, B, C, E and the northern part of Region F in Figure 3.1) and the sprawling mining lands and townships such as Soweto to the south

(Regions D, G and the southern part of Region F in Figure 3.1). Johannesburg as an apartheid city was a city where white people had access to all the major facilities and the black and coloured population did not (Beavon, 2004). Even though the economic and social realities shifted post-apartheid, the geographical divisions (Foster, 2009) and contrast remain (Beavon, 2004).

To settle the dust associated with the Highveld climate and the growing number of mine dumps, large plantations of quick-growing exotic trees (eucalyptus, black wattle and jacaranda) were planted (Turton et al., 2006; Schäffler, Christopher, Bobbins, Otto, Nhlozi, De Wit, Van Zyl, Crookes, Gotz, Tragos & Phasha, 2013). These trees were also used as pit-props in the mines (Turton et al., 2006). The first public spaces where trees were planted in the city were Joubert Park (developed in 1887) (Turton et al., 2006) and the first cemetery called the Braamfontein cemetery (in 1888) (Mawson, 2004). Up to the end of the apartheid era, public park development and street tree planting occurred mainly in the historically affluent northern white suburbs in the city (Mawson, 2004). Cilliers, Cilliers, Lubbe and Siebert (2013) found that more affluent areas have higher vegetation and tree cover than poorer areas, which is a legacy of apartheid as smaller plots were allocated to the poorer marginalised city residents and there was a lack of services in these areas (Cilliers, Drewes, Du Toit & Cilliers, 2011). Schäffler and Swilling (2013) confirm the noticeably unequal distribution in the extent of tree canopy cover between the north and south of the city, where the cover of the northern suburbs is approximately 24.2% and tree coverage in the poorer southern suburbs is approximately 6.7% of the total area (Figure 1.1). Therefore, the focus on greening only the northern suburbs of the city resulted in what is known as the “green divide” between the affluent northern white suburbs and poorer black townships in the south (Mawson, 2004; Schäffler & Swilling, 2013).

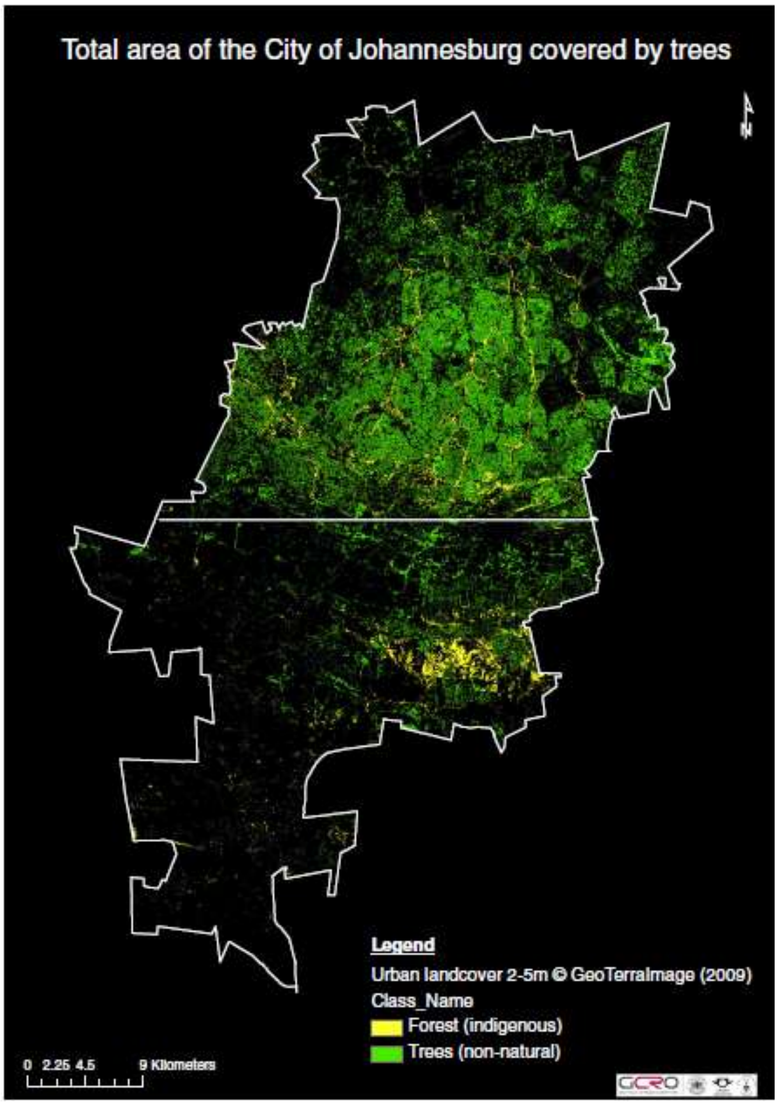


Figure 1.1: The tree cover of CoJ is not uniformly distributed and the distinct differences in coverage between the north and south of the city are clearly visible in this satellite image (Schäffler & Swilling, 2013).

Today, the city claims to be the largest human-made urban forest, with between six and ten million trees in public parks, private gardens and streets, although there is no verifiable statistic of the exact number of trees or the state of the urban forest (Schäffler, 2011). This extensive ecological feature covering approximately 16.1% of the area of the city needs to be recognised and managed as a valuable asset (Schäffler & Swilling, 2013).

1.1.5 Urban forest assessment

Sustainable urban forestry depends on the development and long-term maintenance of the structure, health and benefits of this urban ecosystem (Dwyer, Nowak, Noble & Sisinni, 2000) guided by an urban forestry management plan (Berke, Godschalk & Kaiser, 2006) based on measurable objectives and data. A city cannot effectively manage any objectives if these objectives are not measured (Cozad, McPherson & Harding, 2005). The measurement of objectives depends on available data, which is used to develop assessment or valuation reports. In turn, these reports can provide an analysis or inventory of the tree resource, identifying risks and highlighting benefits and values, leading to structured management planning (Peper, McPherson, Simpson, Gardner, Vargas & Xiao, 2007).

Urban forest assessment involves gathering data during studies and examining aspects such as the types of trees planted, their survival and growth, linked to specific research questions (McPherson, 2014). Typical urban forest assessments such as tree planting surveys involve gathering data on numbers, species and locations of trees planted in parks and streets to develop tree inventories, and monitoring tree survival and growth of trees by measuring tree parameters to determine tree performance and provide information to optimise tree planting locations. Urban forest assessments also include modelling tree growth from tree inventories and growth parameter measurements and developing growth equation relationships and allometric equations. They also include biomass and carbon dioxide calculations using tree-specific allometric equations (McPherson, 2014) and determining the monetary value of the CO_2 based on carbon tax (Stoffberg, 2006). Worldwide urban forest assessments are conducted determining the canopy cover using satellite imagery (Dwyer et al., 2000) and establishing inter alia environmental, economic, ecosystem service and health benefits using a range of specially developed tools such as i-Tree, Capital Asset Value for Amenity Trees (CAVAT) or Street Tree Assessment Tool for Urban Forest Managers (STRATUM) (McPherson et al., 2005; McPherson, Simpson, Xiao & Wu, 2011).

1.2 Justification for the study

Tree planting projects such as the GSTP project are seen to be a cost-effective means to increase the urban forest with the added value that it is instrumental in mitigating the urban heat island effect and climate change (Simpson & McPherson, 1998) as it is considered a proven method for reducing atmospheric CO_2 (McHale, McPherson & Burke, 2007). Therefore, determining the value of a tree planting project as part of the urban forest has value to motivate the capital and management expenditure for future tree planting projects and to develop improvement plans to increase future value.

The GSTP project was completed in 2010 and was deemed a success with the planned number of trees planted by the deadline. Since the first trees were planted in 2006, some of the trees have been growing for up to 14 years and the youngest trees of the project were at the time of writing (2020) at least 10 years old. This period provides sufficient time for the establishment of the trees in their different locations. Therefore, it was appropriate to evaluate the tree planting project at this time. In the light of the number of tree planting projects being initiated worldwide (Nguyen, 2018; Barkham, 2019), this was the ideal time to assess this project, determine if the aim of the project had been realised, identify successes and failures and use the results from the research to develop a strategic plan to ensure successful tree planting projects in future.

Therefore, the overall justification for the study was to improve the canopy cover and value of the urban forest of the CoJ by learning from this project to improve the future success rate of tree planting projects, thereby improving the contribution of urban forests to the mitigation of global warming and climate change. It is anticipated that the outcomes of the study will also be used by other city councils in Gauteng to assess the value of indigenous trees in their respective urban forests and to develop tree planting plans that will encourage higher survival and lower mortality rates of the trees planted.

The management of all public open or green spaces and assets such as street and park trees in the city resides with the JCPZ, a non-profit company of the CoJ. JCPZ have indicated that they do not have an official tree inventory of the trees in the city (Schäffler, 2011), pointing to a lack of measurable data on the urban forest.

Finally, the lack of data on the urban forest functions and economic value of this asset of the city could be the reason for the disregard of this feature by local governments as a tangible urban infrastructure service (Schäffler, 2011). This research study provides a framework and process for future urban forestry research in the city.

1.3 Problem statement

The key problem addressed is that there is currently no guideline for tree planting (based on scientific research) for the optimisation of tree planting projects in the CoJ. The development of such a guideline depends on the evaluation of a tree planting project to provide data to direct the choice of planting location, choice of tree species, tree planting and maintenance specifications and improve the survival rate of trees. Therefore, the success of the GSTP project had to be determined, as there was no data on the status quo, the survival rate of the trees or the value added to the urban forest of the CoJ. The monetary value of the trees planted during the project was unknown. The carbon assessment and value for the entire project had not yet been determined. Knowledge of the value of this project will contribute to the motivation for future tree planting projects and will provide the basis for similar carbon credit initiatives.

To support the guidelines for new tree planting projects, data on the impact of land use, land cover and external site factors on the growth of trees in a city environment was also required. Land use refers to the use of the land on or adjacent to the location where the trees are planted, such as residential or commercial uses, and land cover refers to the physical characteristics covering the surface of the land, such as grass or paving (Ganasri & Dwarakish, 2015). For the purpose of this study, external site factors refer to factors that could affect the growth and placement of trees, such as the requirement of tree maintenance, the effect of pedestrians, conflict or damage caused by infrastructure and the presence of pests and diseases on the trees. There was no such data and therefore the impact of these factors and the interaction of various growth parameters of these trees had to be determined. No allometric equations had been developed for indigenous trees in the CoJ and the growth parameters could be used for this purpose.

1.4 Aim of the study

The aim of the study was to investigate the GSTP project, assess the trees and formulate guidelines for new tree planting projects.

1.5 Objectives of the study

To be able to develop guidelines for new tree planting projects in the CoJ, establish new allometric equations, determine the carbon value and the impact of land use, land cover and external site factors on the growth of these trees, a wide range of data needed to be gathered, assessed and interpreted. Individual but linked objectives were identified to achieve the aim of the study. All the objectives refer to the trees planted during the GSTP project of the 2010 FIFA World Cup in the CoJ. The objectives of this study were:

1. To conduct an inventory of the project.
2. To determine the interaction between age and growth parameters of the trees and to predict future tree growth.
3. To complete a carbon assessment and determine the value of the tree planting project.
4. To determine the influence of land use, land cover and external factors on the growth of trees.
5. To develop guidelines for new tree planting projects to advise new tree planting in the city, improve survival rates and optimise the value added to the urban forest.

1.6 Research questions

The research questions for this study for each of the objectives were as follows:

Objective 1

1.1 What is the survival rate of the trees of the GSTP project?
1.2 Were the aims of the project accomplished, as assessed in 2017?
1.3 How can a tree inventory be developed for this project and used as a template for future tree planting projects?

Objective 2

2.1 how can the VolCalc software program be used to calculate growth parameters of urban trees?

2.2 What is the interaction between age, stem diameter, tree height and crown dimensions of these trees?
2.3 How can these interactions be used to develop new allometric equations for the tree species in the study?

Objective 3

3.1 What is the standing carbon stock estimation for the GSTP project?

3.2 What is the potential projected carbon sequestration over a period of 30 years for different scenarios of the project?

3.3 What is the monetary value of the standing and projected carbon sequestered by these trees?

Objective 4

4.1 How are the trees in the study distributed across the land use, land cover areas and how does external factors such as tree maintenance required, the effect of human influence, conflict or damage caused by infrastructure and the presence of pests and diseases impact their growth?

4.2 Do the land use, land cover and external factors impact the growth of the trees?

4.2 How can any of the land use, land cover or external factor parameters identify aspects for inclusion in tree planting guidelines to improve future tree planting survival rates?

Objective 5

5.1 How can guidelines for new tree planting projects be developed using results from this study, to improve current survival rates and optimise the value added to the urban forest?

1.7 Presentation of the thesis

The thesis covers nine chapters. Subsequent to the project initiation, there were three stages in the research process culminating in the final product of the study. A graphical representation of the research process linking the process with the objectives and chapters is provided in Figure 1.2.

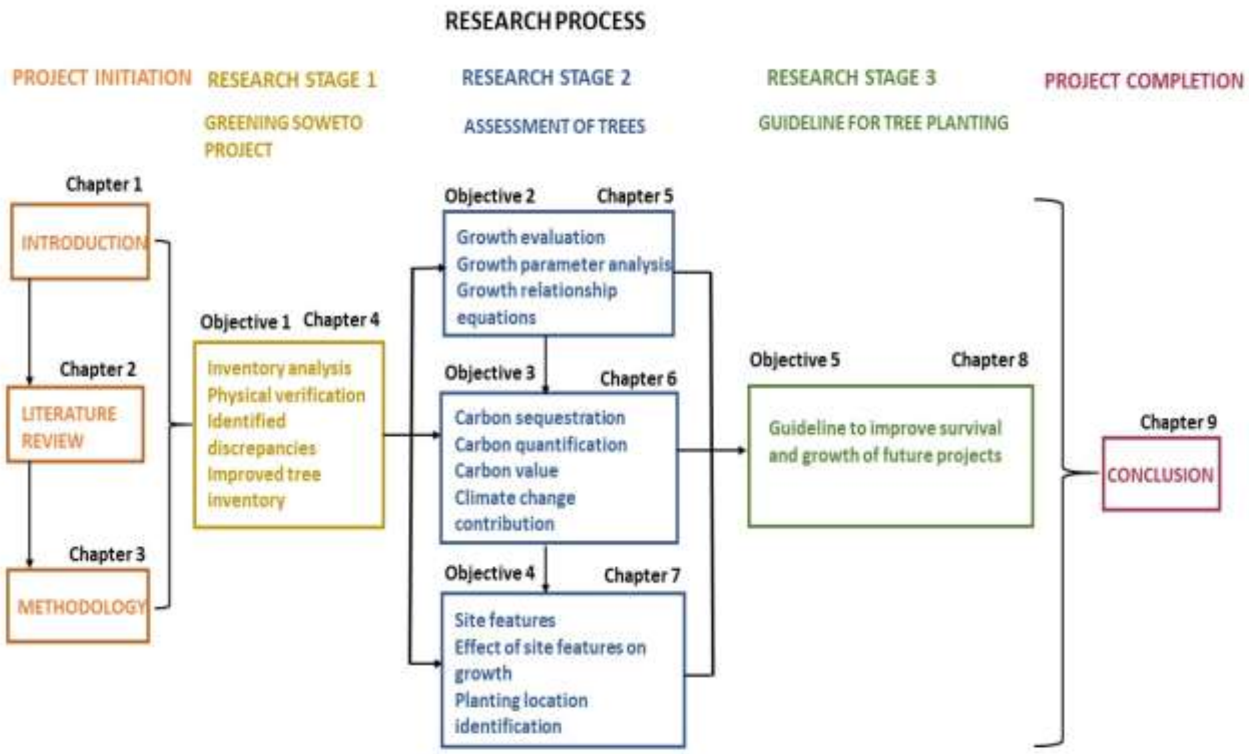


Figure 1.2: Graphical representation of research process

The rest of the thesis is organised as follows:

Chapter 2: Literature review

Chapter 2 provides context to the study with a review of the concept of urban forestry and its contribution to climate change and urban forest assessment and evaluation. Related aspects such as species diversity, urban forestry management and governance, allometry, urban tree growth prediction, land use and land cover are explained and discussed. Tree planting in the city and the impact of tree mortality and survival rates on tree planting projects are also explained. Finally, gaps in the existing research are identified.

Chapter 3: Research design and methodology

The methodology used in the project for each of the objectives is explained and the research design, procedures, techniques, data collection, data analysis, ethical considerations and limitations of the study are discussed.

Chapter 4: Inventory of the Greening Soweto project

The inventory used for the study is analysed and the number of trees planted, the species distribution and the number of existing trees found are verified. The chapter concludes with an example of an inventory suitable for the use of future tree planting projects.

Chapter 5: Growth parameters of the trees and resultant allometry

Chapter 5 focuses on the interaction of the growth parameters of the trees and the aim is to develop new allometric equations for individual indigenous tree species. The interaction of the growth parameters is related to different planting locations to determine optimum planting locations and the interaction of diameter at breast height (DBH) and diameter at ground level (DGL) are determined to confirm whether DGL measurements can replace DBH measurements in research into South African savannah trees. The VolCalc software program used to calculate the growth parameters is explained as useful for the measurement of urban trees.

Chapter 6: Carbon value of Greening Soweto project trees

Chapter 6 provides the carbon assessment for the standing carbon stocks contained in the trees as well as the monetary value of the carbon stocks and the difference in the total carbon stocks and carbon value in the existing trees, the trees on the tree register and an estimation of the trees currently alive for the whole project. The carbon stock is extrapolated over a 30-year period and related to international data. Finally, the discussion concludes by linking carbon sequestration and the value of carbon stocks to climate change mitigation.

Chapter 7: The impact of land use, land cover and external factors on tree growth

The impact of land use, land cover and external factors (tree maintenance required, the effect of human influence, conflict or damage caused by infrastructure and the presence of pests and diseases) on the growth of the trees is discussed. The aim of this chapter is to identify factors that could contribute to the inconsistencies in the growth of these trees and to highlight land use and land cover areas as best locations where trees should be planted in cities.

Chapter 8: Tree planting guidelines

Chapter 8 presents the results of a structured literature review on tree planting strategies in urban environments with the aim to identify appropriate parameters to be included in the development of guidelines for tree planting. It concludes with the presentation of new data (identified in the previous chapters of this thesis) to support and inform the guidelines for new tree planting projects to improve the survival rate of and optimise the value added to the urban forest of the CoJ.

Chapter 9: Conclusion and recommendations

In chapter 9, summaries and conclusions are made and recommendations about this and future tree planning projects are proposed. The new contribution to urban forestry knowledge is highlighted.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The focus of the literature review was to provide a contextual understanding of urban forestry and to highlight the importance of the urban forest and urban forestry research globally, in Africa and specifically in South Africa. Six urban forestry research trends with a focus on international scientific discourses are introduced and provide the background to the study. These research trends highlight inter alia the importance of sustainable management practices, the valuation and assessment of the urban forest and the importance of measurable objectives. The role of urban forestry in mitigating climate change with specific reference to carbon sequestration is debated and the importance of species diversity explored. The literature review also identifies sustainable management approaches to improve the extent and quality of the urban forest. Tree planting strategies and the success of tree planting programmes are investigated and assessed. An in-depth, focused review of international literature was conducted on tree planting in urban environments with the aim to establish an overview and classification of urban tree planting and to highlight aspects that need mention in the development of guidelines for urban tree planting. The literature review provides background information to explain the relevance of each of the chapters in this thesis.

2.2 Urban forestry and green infrastructure

The concept of an urban forest was first developed in Northern America during the 1960s and in Europe the concept was accepted and supported only during the 1990s (Konijnendijk, 2003; Randrup, Konijnendijk, Kaennel Dobbertin & Prüller, 2005). The urban forest includes all the trees and vegetation in streets, parks, privately owned and government-owned gardens, campuses, commercial areas, natural areas, balconies and green roofs (Sangster, Nielsen & Stewart, 2011; Escobedo, Kroeger & Wagner, 2011; Roy, Byrne & Pickering, 2012). According to Konijnendijk and Gauthier (2006), the most widely used definition of urban forestry is "an integrated, city-wide approach to the planting, care and management of trees in the city to secure multiple environmental and social benefits for urban dwellers", developed by Miller (1997).

Urban forestry is a modern approach to urban tree management and focuses on safeguarding the health and vitality of the urban forest and therefore the sustained provision of benefits, now and in the future (Kuchelmeister, 1999). A comprehensive approach to planning and management is required that considers all the trees in the urban area as well as competing land uses, ownerships and community values. This is integral to shifting from reactive to proactive management of the urban forest (Nowak, Stein, Randler, Greenfield, Comas, Carr & Alig, 2010).

Urban forests are vital because of their geographical extent, covering large sections of the urban environment, and because of their proximity to people, they provide substantial environmental, social, economic and recreational benefits to urban dwellers (McPherson, 2006). Before these benefits can be realised, there are several obstacles to overcome. According to Nilsson, Randrup and Wandall (2000), urban sprawl limits green open spaces and space to plant trees in cities is reduced, municipal tree care programmes are inadequately funded lacking resources to monitor and maintain trees, tree maintenance practices are inadequate and poor tree selection exacerbates maintenance problems. They specify that the lack of tree inventories and urban forestry management plans add to the problem and the lack of public awareness and participation in planting programmes compounds the obstacle of sustainable urban forestry.

2.2.1 Global urban forestry research

Universities and state research institutes such as the International Society of American Foresters and the United States Department of Agriculture (USDA) Forest Service lead urban forestry research in North America and in Europe (Konijnendijk, Randrup & Nilsson, 2000). Some universities involved in urban forestry research are The Faculty of Urban Forestry of the University of British Columbia in Vancouver, Canada, well known for producing research on topics such as green spaces and trees for public health and well-being, understanding urban forest ecosystems and maintaining healthy and resilient urban forests (The University of British Columbia, 2020) and the Forest Faculty of the Swedish University of Agricultural Sciences in Alnarp, focusing on management, planning, conservation and forest policy research (Swedish University of Agricultural Sciences, 2020). Scientific production of urban forestry articles is dominated by North American and European authors, with only modest contributions from authors from other continents (Ostoić & Konijnendijk van den Bosch, 2015). According to Konijnendijk et al. (2000) and Bentsen, Lindholst and Konijnendijk (2010), research topics in these northern hemisphere countries deal with the form, function and multiple benefits of urban forestry, tree selection and establishment and the assessment and management of the urban forest. In Europe, the Baltic (Estonia, Latvia and Lithuania) and the Nordic countries (Denmark, Finland, Iceland, Norway and Sweden) are involved in the development of urban forestry research (Konijnendijk, Nielsen, Schipperijn, Rosenblad, Sander, Sarv, Mäkinen, Tyrväinen, Donis, Gundersen, Akerlund & Gustavsson, 2007).

Bentsen et al. (2010) reviewed the scientific contributions published in the journal *Urban Forestry & Urban Greening* and concluded that of the 159 volumes published over a period of 8 years, the contributions were mainly research papers from 33 countries. 90% of the publications were from the northern hemisphere (Europe, Asia, North America, Middle East and North Africa), whereas only 5.0% were from Australia and New Zealand, 3.1% from sub-Saharan Africa and 1.9% from Latin America and the Caribbean. The research topics most frequently covered dealt with green space, green space management and trees (30.2%), almost 14% of the research looked at open green space elements such as trees, parks and wetlands, and 22.6% focused on people's perceptions and preferences. A similar study conducted by Roy et al. (2012) resulted in similar results, confirming that most of the research is conducted in North America, Europe and Asia.

Worldwide, urban forestry research trends can be divided into six scientific discourses:

2.2.1.1 Managerial discourse

The managerial discourse involves all aspects of urban forestry management, including tree health, safety, sustainability and costing (Kuchelmeister, 2000; Ottitsch & Krott, 2005; Nowak et al., 2010; Lawrence & Dandy, 2012). The urban forest is inseparably tied to communities and the environment and it should be managed differently than rural forests (Dwyer, Nowak, & Noble, 2003). The success of urban forestry management requires well-formulated policy, a strong organisation and a stable budget. In the absence of one of these requirements, 'green' issues tend to feature weakly on the political agenda (Ottitsch & Krott, 2005). Policy making on urban forests involves the decision-making process for these areas in terms of formulation, adoption and implementation of objectives, instruments and time frames (Konijnendijk, 1997). Urban forestry management policies provide broad insight into urban forestry practice, outlining the main objectives, goals and principles for management of urban forests, and include a variety of urban forest strategies, regulations, programmes and plans to assist individual cities in the management of the urban forest (Gudurić, Tomićević & Konijnendijk, 2011).

Kenney et al. (2011) state that canopy cover should not be the only indicator used to drive urban forestry management plans (UFMPs); rather, a range of specific goals should be identified and targets or criteria defined with specific performance indicators of success. The performance indicators enable measurement of progress towards achieving the key objective for each criterion. In a study comparing urban forestry in North America and Europe, the authors concluded that both view urban forestry as multifunctional and multidisciplinary in character but that community forestry is practised more often in North America than in Europe (Konijnendijk, Richard, Kenney & Randrup, 2006).

Research involving the managerial discourse has been prominent in North America and Europe on topics such as urban forestry management and urban forestry policies as well as healthy, resilient and safe urban forests and the justification of costs involved in management in the US (Konijnendijk, Sadio, Randrup & Schipperijn, 2004; Gibbons, 2014), Nordic countries such as Denmark, Norway and Sweden (Konijnendijk et al., 2007), Canada (Conway & Urbani, 2007; Millward & Sabir, 2010; Ordóñez & Duinker, 2013; Steenberg, Duinker & Charles, 2013), Germany (Gudurić et al., 2011), European countries such as Belgium, Italy, Sweden and England (Lawrence, De Vreese, Johnston, Konijnendijk van den Bosch & Sanesi, 2013) and Serbia (Gudurić et al., 2011; Lakicevic, Srdjevic, Srdjevic & Zlatic, 2014).

In the southern hemisphere research involving the managerial discourse of urban forestry regarding healthy, resilient and safe urban forests has been conducted in Newcastle, Australia (Stewart, O'Callaghan & Hartley, 2013) and 30 cities in New Zealand (Stobbart & Johnston, 2012). In West and sub-Saharan African cities, rapid urban population growth combined with limited available land and poor implementation of government policies are some factors affecting urban forest development (Fuwape & Onyekwelu, 2011; Chishaleshale, 2012).

In an analysis of the national policies mentioning trees and urban forestry in South Arica, Guthrie and Shackleton (2006) reveal that there were relatively few policies that dealt with urban tree planting and maintenance and where there were such policies, they were rarely translated into specific guides, standards and actions for implementation. Local municipalities are responsible for urban forestry and are continuously planting trees in urban areas, even though they lack funds and, in some instances, expertise for appropriate planning and implementation (McConnachie & Shackleton, 2010). Tree planting programmes are not guided or informed by any research programme and take limited cognisance of the economic and social dimensions of the specific area influencing the distribution of these trees and their subsequent management negatively.

Findings of a study conducted in local municipalities of the Limpopo and the Eastern Cape provinces indicate that urban trees are not recognised as important in existing government institutions. These local municipalities are not managing their urban trees in a planned and structured manner due to constraints such as a lack of funding, equipment, personnel and political support (Chishaleshale, 2012). According to Schäffler et al. (2013), the City of Tshwane (in the same province as and adjacent to the study site) has an urban forestry policy that guides the management of the trees in the city as well as new tree planting initiatives.

2.2.1.2 Civic involvement discourse

The civic involvement discourse deals with the needs and involvement of residents to create pleasant urban areas and spaces (Coles & Bussey, 2000; Gudurić et al., 2011). The promotion and establishment of an effective urban forestry strategy requires an understanding of the relationship of the social parameters and values of the urban forest, which can only be determined by involving residents in the strategy (Coles & Bussey, 2000). Dwyer, Nowak and Watson (2002) confirm that community involvement is critical for the continued vitality of urban forests.

Three recurring biophysical challenges of urban forests are insufficient nutrients, lack of water and vandalism, all of which can be improved by communities and homeowners. There are significant social factors that affect urban tree health, providing evidence of the importance of community involvement in urban forests (Jack-Scott, Piana, Troxel, Murphy-Dunning & Ashton 2013). Community group participation has proven integral to the success of new tree planting programmes as well as the maintenance of these trees (Dwyer et al., 2002; Greene, Millward & Ceh, 2011).

It is found that in general, people of all ages, gender, race and income prefer to have trees on their property and in their community (Lohr, Pearson-Mims, Tarnai & Dillman, 2004; Zhang & Zheng, 2011; Conway & Bang, 2014), but individuals with higher education have a tendency to like more trees (Zhang & Zheng, 2011). That study concluded that even though there is a significant demand for urban trees, the community is not as willing to carry the financial burden (Zhang & Zheng, 2011). Conway and Bang (2014) conclude that even though communities living in neighbourhoods filled with trees indicate a tendency to enjoy their environment, they do not support municipal tree planting policies that are focused only on increasing tree numbers and indicate an unwillingness to bear costs associated with risks associated with large trees.

The most important benefit of urban trees that communities perceive is their ability to provide shade and cooling of warm areas and, secondly, trees help them feel calmer. This is an indication that communities appreciate not only the practical benefits, but also the aesthetic value of trees (Lohr et al., 2004).

In the USA there are currently more than 3 400 communities certified as part of the Tree City USA programme. This programme provides a framework for communities to manage and expand public trees and their activities include tree planting and public awareness programmes. They also assist in collecting tree inventory data and get involved in activities to determine urban forest benefits (Zhang & Zheng, 2011).

In the northern hemisphere research relating to the civic involvement discourse was conducted in Connecticut and dealt with the success of stewardship and how community group dynamics affect street tree survival (Jack-Scott, Piana, Troxel, Murphy-Dunning, & Ashton, 2013). Research was also conducted in Alabama, USA, giving a perspective of municipal officials and policy makers on urban tree programmes (Zhang & Zeng, 2011). In the United Kingdom, Coles and Bussey (2000) identified and valued urban woodlands according to their social significance to the users. In Ontario, Canada, Conway and Bang (2014) conducted research on the support of residents for municipal tree policies, and in the continental USA Lohr et al. (2004) conducted a study to determine how residents rate the benefits and problems associated with urban trees.

Present-day forestry management in West Africa has been influenced by colonial forest policies, securing forest resources for the government without participation of the local population. This has resulted in the indifference of communities to urban forest development and the occasional destruction of the forests (Amanor, 2004). The residents of Benin City in Nigeria has indicated a positive appreciation for the ecosystem service benefits provided by urban trees (Arabomen, Chirwa & Babalola, 2020).The only research referring to community benefits derived from urban forestry in South Africa was found cited in Web (1999), stating that a multifunctional park design and management system including urban forestry in the park design, found in Durban, KwaZulu-Natal benefited local communities.

2.2.1.3 Ecosystem services discourse

Research describing the provision of services by ecosystems (such as the carbon forest) and the quantification and valuation of benefits associated with these services is referred to as the ecosystem services discourse (Dwyer, McPherson, Schroeder & Rowntree, 1992; Kuchelmeister, 2000; Nowak & Dwyer, 2007; Wolf, 2007; Escobedo & Nowak, 2009; Roy et al., 2012; Silvera Seamans, 2013) and others.

Ecosystem function refers to the capacity of natural processes and components to provide goods and services that satisfy human needs (Wang, Bakker, De Groot & Wörtche, 2014) and describe environmental benefits of the urban forest in terms of economics and conservation (Roy et al., 2012). Urban tree benefit studies describe the link between ecosystem functions and human benefits (Roy et al., 2012).

Some authors make a distinction between urban forest benefits and ecosystem services. Roy et al. (2012) describe tree benefits as economic, social, health, visual and aesthetic benefits and identify ecosystem services as carbon sequestration, air quality improvement, stormwater attenuation and energy conservation.

There is scientific proof that trees provide a wide range of benefits to cities (Miller, 1997). These benefits include the absorption of GHGs such as atmospheric carbon dioxide, the mitigation of the negative effects of air pollution, the protection of local watersheds and improvement of stormwater management as well as the reduction in ambient air temperatures by providing shade on hard surfaces and surrounding structures (Miller, 1997; Xiao &

McPherson, 2002). Street trees also provide beauty and have been related to a variety of psychosocial benefits, which result in increased property values, higher occupancy of rentable space and increased foot traffic in commercial areas (Miller, 1997). Other benefits include reductions in ultraviolet radiation, and even social benefits such as the reduction in levels of crime (Dwyer et al., 1992; Kuo & Sullivan, 2001; Nowak & Dwyer, 2007; Wolf, 2007), human health improvement and general well-being (Tzoulas & James, 2010, Wolf, 2007; O'Brien, Williams & Stewart, 2010).

A wide variety of research papers are available to underpin the scientific proof of urban forest and tree benefits and the value of ecosystem services of trees and the urban forest. Table 2.1 is a summary of these benefits with a brief description of the benefit provided by the urban forest and trees.

Table 2.1: Summary of benefits derived from urban forest and trees

Benefit	Description	Reference
Environmental benefits/ecosystem services		
Stormwater mitigation	The presence of street trees reduces stormwater volume and runoff, flood damage and recharges groundwater as tree pits provide surfaces where water can infiltrate. Leaves and branches intercept, absorb and temporarily store water before it can evaporate or infiltrate at a slower rate. Evergreen trees intercept more than deciduous trees.	Armson, Stringer and Ennos (2013), McPherson et al. (2011), Soares, Rego, McPherson, Simpson, Peper and Xiao (2011), Tallis, Taylor, Sinnett and Freer-Smith (2011), McPherson et al. (2005), Killicoat and Stringer (2002), Xiao and McPherson (2002), McPherson and Simpson (1999)
Air quality improvement	Trees, and particularly large evergreen trees, capture airborne pollutants such as ozone, carbon monoxide, sulphur dioxide, nitrogen dioxide, carbon dioxide and airborne or suspended	Goosen (2016), McPherson et al. (2011), Nowak (2006), Soares et al. (2011), Tallis et al. (2011), Jim and Chen (2009), McPherson et al. (2005), Killicoat and Stringer

	particles, thereby improving air quality in the vicinity of the tree's mass.	(2002), McPherson, Simpson, Peper and Xiao (1999), McPherson, Nowak and Rowntree (1994)
Ecology/habitat/ biodiversity provision	Street and park trees enhance biodiversity by providing food, habitat and landscape connectivity for urban fauna and flora.	Ikin, Knight, Lindemayer, Fisher and Manning (2013), Davis, Taylor and Major (2012), McPherson et al. (2011), Rhodes, Ng, De Villiers, Preece, McAlpine and Possingham (2011), Young, Daniels and Johnston (2007), Alvey (2006), Burden (2006), Lohr et al. (2004)
Micro-climate improvement	Trees in the city provide shade, reduce solar radiation, modify the micro-climate, reduce air temperature and glare, control wind and ameliorate the urban heat-island effect. The leaves and branches of the tree intercept water. Roots absorb and temporarily store water, evapotranspiration occurs from the stomata and lenticels on tree leaves and stems, and the water exits the plant in vapour form. Water also gradually soaks into the soil and contributes to the modification of the micro-climate.	Escobedo et al. (2011), Rhodes et al. (2011), Seitz and Escobedo (2011), Burden (2006), McPherson, Nowak, Souch, Grant and Rowntree (1997)
Carbon dioxide ecosystem services	Trees store and sequester tons of carbon in their tissues and act as sinks of carbon dioxide offsets and GHG emissions and remove carbon dioxide. Carbon	Grace and Basso (2012), Liu and Li (2012), Soares et al. (2011), Moore (2009), Stoffberg, Van Rooyen, Van der Linde and Groeneveld (2010), Burden (2006),

	sequestration plays a major role in mitigating climate change.	McPherson et al. (2005), Johnson and Gerhold (2003), Brack (2002), Nowak and Crane (2002), McPherson (1998)
Energy saving and optimisation	Trees provide energy savings through their shading and cooling effects in summer and the wind chill protection they offer in winter. Homes and buildings with appropriate tree shade experience a reduction in summer energy use and seasonal cooling compared to homes without shade. The reduction in energy use has the knock-on effect of reduced CO_2 and pollutants such as nitrogen dioxide and volatile organic compounds, due to reduced energy generation from both summer cooling and winter heating demands of urban dwellings.	Soares et al. (2011), Pandit and Laband (2010), Donovan and Butry (2009), Moore (2009), Shashua-Bar, Erell and Pearlmutter (2008), McPherson et al. (2005), McPherson et al. (1998), McPherson et al. (1994)
Noise reduction	Trees can, to a limited extent, reduce noise from road traffic.	Tallis et al. (2011), Bolund and Hunhammar (1999)
Economic benefits		
Increasing property value	Property value, land value, neighbouring property value, reducing the “time on the market” for selling property and property tax increases are all aspects where trees influence property value.	Pandit, Polyakor, Tapsuwan and Moran (2013), Soares et al. (2011), Sander, Polasky, and Haight (2010), Wolf (2009, 2007), Zhang, Hussain, Deng and Letson (2007)

Increasing economic activity	Trees in cities contribute to the character of the city, which in turn contributes positively towards tourism revenue, business activity and economic vitality. Consumers spend more when shopping in retail developments that include trees in the landscape.	Kaoma and Shackleton (2014), Wolf (2009, 2007), Burden (2006), Shackleton, Chinyimba, Hebinck, Shackleton and Kaoma (2015)
Reducing expenditure	The presence of trees is linked to a reduction in energy, electricity and fuel expenditure (heating and cooling) and medical expenses due to allergies from pollution, by local governments.	Tallis et al. (2011), Ferrini and Fini (2011), Donovan and Butry (2009), Akbari, Pomerantz and Taha (2001)
Carbon trade	Trees provide potential for future carbon offsetting and trading in carbon credits.	Van Rooyen, Van Rooyen and Stoffberg (2013), Poudyal, Siry and Bowker (2012), Stoffberg et al. (2010), Stoffberg, Van Rooyen, Van der Linde and Groeneveld (2009)
Increasing worker productivity	Workers are more productive, and absenteeism is reduced when workers have views of trees and green space. Time spent in green space during work improves the overall well-being of workers.	Gilchrist, Brown and Montarzino (2015), Lottrup, Stigsdotter, Meilby and Claudi (2015), Kaplan (1993)
Health benefits		
Physical health improvement	By providing settings (parks with trees) for physical exercise and an active lifestyle in urban areas, the physical health of the residents can be improved. Faster physical recovery from	Donovan, Butry, Michael, Presremon, Gatziolis and Mao (2013), Sarajevs (2011), Zhang et al. (2007), McPherson et al. (1999)

	illness is reported where people are in contact with natural landscapes and trees.	
Psychological health improvement	Psychological well-being such as the reduction of stress and the creation of relaxed psychological states are directly linked to urban parks and green space. The interaction of nature and the presence of plants have a positive effect on the human mind.	Ernstson (2012), Grinde and Patil (2009), Lohr et al. (2004), Dwyer, Schroeder and Gobster (1991)
Hospitalisation recoveries and admission reduction	Fewer complications and faster recovery at hospital having windows with tree views are reported, respiratory hospital admissions are averted and recovery from surgery is improved.	Grinde and Patil (2009), Tiwary, Sinnett, Peachey, Chalabi, Vardoulakis, Fletcher, Leonardi, Grundy, Azapagic and Hutchings (2009), Ulrich (1984)
Quality of life of the elderly	The quality of life of the elderly in long-term care is improved when they are exposed to a garden environment with trees and flowers. A green exterior environment contributes positively towards the behaviour of older Alzheimer patients.	Aldous (2007), Rappe and Kivelä (2005), Mooney and Nicell (1992)
Social benefits		
Quality of life of communities	Trees enhance quality of urban life, spiritual experiences, make the urban environment more pleasant to live and work in, enhance the community's sense of social identity and increase community interaction.	Van Dillen, De Vries, Groenewagen and Spreeuwenberg (2012), Mullaney, Lucke and Trueman (2015), Tarran (2009), Burden (2006)

Traffic Improvements	Trees provide a visual and physical barrier between motorists and pedestrians, thereby improving community safety. This defining edge reduces crashes and injuries on urban roadways and reduces speed of travelling vehicles.	Kadir and Othman (2012), Tarran (2009), Burden (2006)
Recreation provision	The urban forest provides substantial outdoor leisure and recreational opportunities for urban dwellers. Parks and other green open spaces with ample trees are preferred spaces for bicycle, walking and running trails.	Dwyer et al. (1992), Roy et al. (2012), Gudurić et al. (2011), McPherson, Simpson, Xiao and Wu (2008), Burden (2006)
Introducing nature into urban environments	Street and park trees contribute to nature in the city, they create a connection between vegetation strips in cities and the environment outside of the city, providing corridors for the dispersal of small animals and birds as well as insects. Trees provide habitat and food for urban wildlife, promote environmental responsibility and provide opportunities for inner city residents and especially children to experience nature.	Mullaney et al. (2015), McPherson et al. (2011), Angold, Sadler, Hill, Pullin, Rushtin and Austin (2006), Burden (2006), Gorman (2004), Lohr et al. (2004)
Crime reduction and public safety improvement	Reduced crime and increased public safety are often associated with suburbs with ample large street trees. Abundant street trees send signals to a potential criminal that the neighbourhood is	Mullaney et al. (2015), Donovan and Prestemon (2012), Troy, Grove and O'Neil-Dunne (2012), Tarran (2009), Wolf (2009), Kuo and Sullivan (2001)

	better cared for and therefore a criminal is more likely to be caught.	
Aesthetic benefits		
Scenic qualitycontributions	Trees contribute to the aesthetic beauty of a suburb and improve the scenic quality of a suburb as preferred by residents. Deciduous trees create seasonal interest in suburbs in contrast to an evergreen tree environment.	Mullaney et al. (2015), Zhang et al. (2007), Burden (2006), Todorova, Asakawa and Aikoh (2004), Tyrväinen et al. (2005)
Provision of sense of place & identity	Involvement in tree planting programmes provides residents with a sense of place and identity and can alleviate some of the hardships of poor living conditions. Trees also provide privacy in areas where needed.	Mullaney et al. (2015), Roy et al. (2012), Todorova et al. (2004), Dwyer et al. (1992)

Trees provide environmental, social, economic, aesthetic and health benefits that are often discarded because their monetary value is not known (Dwyer et al., 1992). Conversely, pressures on municipal budgets drive management decisions aimed at reducing expenditures. Often trees are prematurely removed from the urban forest and are not replaced; others are inadequately maintained. This is often a result of financial management where reducing costs outweighs the costs to increase tree health and the ecosystem services they provide over the long term (Carreiro & Zipperer, 2008).

Hirokawa (2012) describes urban forests as an important component of green infrastructure and stresses the benefits of urban trees and therefore the protection of urban forests to maximise the economic (monetary) value of green infrastructure to local governments. However, some benefits are debated in the literature. Urban plantings that increase allergens, host pests, reduce safety, increase GHG emissions or become invasive are known as ecosystem dis-services (Lyytimäki, Petersen, Normander & Bezák, 2008). Green spaces in cities are known for their localised cooling effect; however, the amount of water needed for irrigation (specifically in arid climates) counteracts the value contribution (Pataki, Carreiro, Cherrier, Grulke, Jennings, Pincetl, Pouyat, Whitlow & Zipperer, 2011). There is a scarcity in empirical evidence that urban forests consistently improve local-scale air quality in urban environments. No scientific consensus has been found that urban trees reduce asthma by improving air quality and in some people, trees can have the opposite effect (Eisenman, Churkina, Jariwala, Kumar, Lovasi, Pataki, Weinberger & Whitlow, 2019). In cool climates trees increase carbon emissions from residential building energy use (Erker & Townsend, 2019).

Many of the urban forest ecosystem services are directly related to the number of healthy leaves on a tree. Therefore, tree cover becomes a simple measure of the extent of the urban forest and consequently the magnitude of services provided by the forest (Nowak & Greenfield, 2012).

Quantifying tree canopy cover has been identified as one of the first steps in the management of the urban forest (Escobedo & Nowak, 2009; Nowak et al., 2010; Schwab, 2009). Canopy cover data, in conjunction with gathering structural data at ground level (e.g. tree height, stem diameter, species composition and tree health) will provide opportunities for comprehensive urban forest planning and management (Nowak, Rowntree, McPherson, Sisinni, Kerkmann & Stevens, 1996). According to Roy et al. (2012), most of the urban forestry research conducted addresses the valuation of ecosystem services provided by the urban forest, and air quality and carbon-related ecosystem services receive the most attention in research studies.

Urban forestry valuations have been conducted in a large number of cities in the northern hemisphere, such as Colorado and California (McPherson et al., 2005; McPherson et al., 2011), New York (Peper, McPherson, Simpson, Gardner, Vargas & Xiao, 2007), Los Angeles (McPherson et al., 2008), Lisbon in Portugal (Soares et al., 2011), Toronto, Canada (Millward & Sabir, 2010) and Minneapolis in Minnesota (Cozad et al., 2005). Studies have also been conducted in developing countries such as Bhopal, India (Dwivedi, Rathore & Dubey, 2009) using a range of valuation systems such as Helliwell, CAVAT and the i-Tree peer-reviewed software suite (Sarajevs, 2010; Natural England, 2013).

Limited research on benefits of urban forests has been conducted in Africa and South Africa. Fuwape and Onyekwelu (2011) have identified tangible (timber and food) and intangible (ameliorating high temperatures and creating windbreaks) benefits provided by the urban forests in West and sub-Saharan African cities. These benefits can contribute directly to alleviating poverty and enhancing the well-being of the inhabitants in the area. Unfortunately, these benefits are often disregarded as the development of self-housing projects (slums and shanty towns) without any municipal services results in illegal cutting down of trees for fuel wood and timber, preventing the realisation of their benefits (Fuwape & Onyekwelu, 2011).

Residents of low-income neighbourhoods in selected small towns in South Africa do recognise and appreciate the multiple benefits of trees in their environment, but a large number of residents in the same areas expressed concern that trees provide sites for criminals to hide (Shackleton et al., 2015).

2.2.1.4 Biodiversity discourse

Biodiversity is seen as one of the ecosystem services of urban forests (Alvey, 2006; Clarke, Jenerette & Davila, 2013). Conserving biodiversity in urban areas is an important global issue as it can mitigate the negative environmental impacts of urbanisation. Conservation of local and regional species assist the community in understanding the natural processes that govern global and human sustainability (Hostetler, Allen & Meurk, 2011; Barrico, Castro, Pereira Coutinho, Gonçalves, Freitas & Castro, 2018).

Historically, biodiversity management in cities is concentrated in urban conservation areas (Hostetler et al., 2011). However, research has indicated that urban and suburban areas can contain relatively high levels of biodiversity (Araújo, 2003; Alvey, 2006). City planners and urban forestry managers must recognise the potential for urban areas to harbour high levels of biodiversity (including fauna and flora) and promote urban development by incorporating an ecological perspective into their management plans (Barrico et al., 2018). This will assist in the development of management practices that increase and preserve biodiversity in the urban forest (Alvey, 2006) and enhance human health and global environmental quality (Barrico et al., 2018). Land use governance and the age of the trees in the urban forest influence vegetation patterns, which directly influence biodiversity, requiring policies and management attention to conserve and improve biodiversity (Hostetler et al., 2011; Clarke et al., 2013).

In the United States, the tree canopy of the metropolitan areas collectively accounts for nearly 25% of the nation's total tree canopy. At the rate of current urbanisation, this number should increase (Dwyer et al., 2000) and urban areas will become even more important in conserving and promoting biodiversity (Alvey, 2006).

Research on the biodiversity discourse was conducted in Coimbra, Portugal (Barrico et al., 2018), Europe (Araújo, 2003) and Los Angeles (Clarke et al., 2013). However, there is a lack of research on biodiversity in urban forests in Africa and South Africa. A literature search revealed that limited research on the prevention of the loss of biodiversity in urban areas with specific reference to urban forests were conducted in South Africa. Cilliers et al. (2013) commented on research aimed at changing the perceptions of local governments and politicians towards ecosystem services and biodiversity and indicated that studies have been conducted in Durban and Cape Town, South Africa. Shackleton (2016) showed that non-native trees in Grahamstown in the Eastern Cape had a significantly higher prevalence of bird species than indigenous trees and indicated a positive relationship between street tree species richness and bird species richness.

2.2.1.5 Urban planning discourse

The urban planning discourse focuses on achieving sustainability and strategic planning within the urban forestry context (Clark, Matheny, Cross & Wake, 1997; McPherson, 1998, Dwyer et al., 2000; Nowak, Noble, Sisinni & Dwyer, 2001). Clark et al. (1997) define the concept of sustainable urban forestry as “the naturally occurring and planted trees in cities, which are managed to provide the inhabitants with a continuing level of economic, social, environmental, and ecological benefits today and into the future”. McPherson (1998) states that a sustainable urban forest should constitute mostly healthy trees with a wide distribution of tree age and species diversity that are well adapted to local conditions. He also concludes that human involvement is paramount in the sustainability of the urban forest as people influence when and how development occurs, and they select the species to plant and the level of maintenance and overall management.

In a comprehensive study on urban forest sustainability in China it was found that the urban forests play a major part in meeting the needs of humans in the present and for future generations, without sacrificing ecological integrity (Ning, Nowak & Watson, 2017). Dwyer et al. (2000) and Nowak et al. (2001) state that the most powerful forces directly affecting urban forestry sustainability are land use policy and land use change.

Clark et al. (1997) presented a model for urban forest sustainability, based on the premise that city trees provide a wide range of benefits and maintaining these benefits requires human intervention within defined boundaries. The success of this model relies on the vegetation resource component, a community framework and management of the vegetation resource. The vegetation resource is the “engine that drives urban forests” and refers to the composition, extent and distribution of the trees within the urban forest (Clark et al., 1997; Kenney et al., 2011). The urban community framework refers to the creation of a shared community vision for the urban forest, the community understanding of the benefits of urban trees and the importance of the community’s involvement in managing the urban forest. The final component of a sustainable urban forest is the management of the urban forest as a resource and includes the programmes, staff and policies that direct the management objectives (Clark et al., 1997; Kenney et al., 2011). Clark and Matheny (1998) used the model for sustainability and developed key performance indicators such as tree age and species diversity and distribution for the vegetative resource component of the model; community involvement and organisational interaction as the community framework, and managerial aspects such as funding, policies and implementation thereof to measure sustainability.

Dwyer et al. (2000) list six elements that are fundamental to achieve urban forest sustainability. These elements are detailed inventories and monitoring of urban forest resources, exchanging ideas among urban forest managers and the community, collaboration with interest groups, knowledge and understanding of urban forest structures and their impacts on benefits, focus on urban forest health, and providing as much information as possible to the community and all the urban forest interest groups. Key elements in proving urban forestry sustainability rely on the availability of data of the urban forest structure and composition (McPherson, 1998).

The urban forest structure is defined by the composition and distribution of the tree species as well as the size, distribution and condition of the trees in the urban forest (Nowak, 1994). Natural factors such as wind/drafts, moisture and soil characteristics, and the management of the tree resource will influence the condition of the structure (Zipperer, Sisinni, Pouyat & Foresman, 1997). Urban foresters cannot control natural factors, but should focus on the control of species and age-class distribution, tree condition and creating optimum growth conditions (above and below ground) for trees to ensure sustained supply of environmental, social and economic benefits (Kirnbauer, Kenney, Churchill & Baetz, 2009).

Elmendorf, Cotrone and Mullen (2003) confirm that the sustainable management of urban forests relies on the inclusion of all publicly and privately owned trees and depends on the local government as the custodian of the urban forest to involve the community in organised forums. Each urban forest has a unique and diverse character due to its location, environmental conditions, species diversity and the different land uses. Each urban forest therefore requires a custom urban forest management strategy to ensure sustainability and the realisation of the benefits associated with the urban forest and state that not only biological aspects (tree growth) are important, but social and political concerns must jointly be addressed to sustain urban forest health and structure in the 21st century (Dwyer et al., 2003).

The literature review revealed that no studies on urban forest sustainability in Africa and South Africa could be found.

2.2.1.6 Green infrastructure discourse

Research based on optimal use of green open space and the cost-effective delivery of benefits is discussed in the green infrastructure discourse (Tzoulas & James, 2010; Ostoić & Konijnendijk van den Bosch, 2015). Several studies have confirmed that urban green spaces as a resource have a positive effect on urban residents as they improve the environmental quality of life, promote public health by means of active and passive recreation and improve urban tourism (Ely & Pitman, 2014). Ostoić and Konijnendijk (2015) link this discourse to the urban planning discourse but due to the specific identity of green infrastructure, it has been made a discourse on its own. Research papers on this topic have been published only since

2010, when Tzoulas and James (2010) indicated that trees are important in parks concerning cultural and recreational services provided by green open space.

Green open space and other green assets in a city are not luxury items but connect communities to nature. Therefore, these need to be managed and used optimally to conserve these spaces by protecting ecosystem values and functions and providing diverse recreational, social and economic benefits to residents (Benedict & McMahon, 2001).

The literature review identified only one study on the valuation of the impact of trees on green infrastructure in the CoJ, South Africa (Schäffler, 2011; Schäffler & Swilling, 2013). Schäffler and Swilling (2013) state that the CoJ planned to expand the urban forest as its primary ecological asset; however, there was no clear approach to planning for it as green infrastructure. The literature review did produce a few other studies on the optimal use of green open space and the cost-effective delivery of benefits in Africa and South Africa. De Wit, van Zyl, Crookes, Blignaut, Jayiaya, Goiset, et al., (2012), stated in a study conducted in Cape Town, South Africa, that by investing in urban natural assets relatively high economic value in city economies can be leveraged. In a study in Potchefstroom, in the Noth-West Province of South Africa, it was founded that green spaces had a negative impact on site-scale, but a positive impact on neighbourhood-scale in affluent residential areas of the town (Cilliers & Ciliers, 2015). These studies did not specifically refere to trees. A literature review study identified that research is being conducted on green infrastructure in Africa, and identified that only 38% of the countries in sub-Saharan Africa had research conducted in them and identified barriers and challenges relating to sustainable delivery of ecosystem services.

2.2.2 Urban forestry research in Africa and South Africa

Hosek (2014) indicates that urban forestry research in Africa has been published on a continuous basis only since 2006, with 12% of the publications from Kenya, 14% from Rwanda and Ethiopia combined, 20% from Nigeria and 39% from South Africa.

In South Africa, urban forestry research includes identifying benefits and values of trees in small towns, urban forestry policy development, urban forestry management and history as well as growth prediction, growth modelling and carbon sequestration. Urban forest development policies for low-cost housing developments in South Africa exclude green infrastructure elements such as tree planning and green open space provision. This reinforces the disparity between low-cost housing and affluent housing developments (Shackleton et al., 2015).

Tree planting projects in urban areas are not seen as important by government. They are implemented without analysing the benefits and constraints of the intervention and do not receive the profile and research focus that they require and deserve (Shackleton, 2006). Confirming these findings, Gwedla and Shackleton (2015) reiterate that the size of the urban forest in some of the towns in the Eastern Cape relates to the lack of policy frameworks at local level, insufficient funds and the lack of adequate space in the planning phase of new residential developments.

Popular media articles (Brodie, 2013; Disemelo, 2013) have debated the claim by the CoJ that the urban forest of the city is the largest human-made forest in the world and has over 10 million trees throughout the city (City of Johannesburg, 2007; City of Johannesburg, 2011). This could not be verified as the literature review did not identify any scientific research to prove the statement of the CoJ. The claim of 10 million trees could not be verified either, as exact numbers in the form of a verified tree inventory are not available. Shackleton (2012) states that the boast of the CoJ was substantiation that urban forestry is happening in South Africa, but the absence of scientific prudence in international literature limits worldwide comparisons.

In a paper presented at a symposium on trees in the landscape, held in Stellenbosch, South Africa, Rist (1993) declared that a project would be launched to survey the tree population in the CoJ and establish a computerised tree inventory and management system to be used to inform an urban forestry management plan. This project was cancelled, together with all special projects in the parks department of the city, due to a new government regime in 1994 and no proof could be found of such a computerised program (Buff, 2017). Schäffler et al. (2013) used the Geo Terra Image 2012 Urban Land Cover dataset and determined that trees cover approximately 16.1% of the total area of Johannesburg's 164 458 ha, of which 24.2% of the historically wealthy northern suburbs are covered in trees, with only 6.7% of the poorer southern quadrant being covered by trees.

A valuation of the carbon stock of the urban forest of the CoJ was conducted by Schäffler and Swilling (2013) using a 50 × 50 m^2 pilot study site representative of an urban tree stand. Tree diameter at breast height, stem lengths and the percentage branch volume of the total tree volume were calculated to determine the carbon stocks. They extrapolated the results to the city scale and used the market-related carbon prices at the time of their study to determine the value. The results indicate that the total carbon stock could be estimated at 5.3 million metric tons valued at €82 269 015 using a market-related carbon price of €15.42 per ton. The authors concluded that the results could not equate to a true reflection for the entire city and were to be viewed as an estimation at best.

2.3 Urban forestry valuation and assessment

The main aim of sustainable urban forestry is to ensure that forest structure, composition, health and benefits are maintained throughout the urban ecosystem, over an indefinite period. Comprehensive and adaptive management approaches are required to improve the urban forest resource as an environmental asset to the city and an urban forest assessment provides the basis from which such a management plan could be developed (Dwyer et al., 2000). As discussed, urban forestry management planning requires measurable objectives and data to manage any objectives effectively. Therefore, understanding the size, distribution and structure of the urban forest is critical to quantifying the value of the asset and to managing this resource effectively (Cozad et al., 2005).

Tree assessment reports provide results such as a city-wide tree census or inventories, including an analysis of the tree resource and structure with relative benefits and values that lead to structured management planning (Peper et al., 2007) or assessments of the urban forest canopy to inform new tree planting, budgets and citizen engagement (Plan-It Geo, 2014). Tree assessments are also conducted with the aim of assessing the risk of the urban forest with regard to tree failure and identify mitigating actions to prevent damage to property and people (Quantified Tree Risk Assessment, 2014; Smiley, Matheny & Lilly, 2012).

A wide variety of urban forest tree assessment reports have been published in locations such as Minneapolis, Minnesota (Cozad et al., 2005), New York City (Peper et al., 2007) and Mississauga, Ontario (Plan-It Geo, 2014). The literature review revealed no tree assessment reports published for any city in Africa or South Arica. However, research articles have been published on tree assessment in South African cities and towns such as the city of Tshwane (Stoffberg, 2006) and the towns Bela-Bela and Tzaneen (Shackleton et al., 2015).

According to Nowak (2013), the structure or composition of the urban forest could be assessed using two different methodologies: a bottom-up approach and a top-down approach. The top-down approach provides data to determine the canopy cover of the urban forest, and the bottom-up approach is used during a tree census to collect data and compile a tree inventory. The bottom-up approach requires field-based assessments and quantifies the physical structure of the forest by determining the individual species composition, condition and number of trees in the forest. The top-down approach assesses the canopy cover by means of aerial or satellite imagery, aerial photos and maps as well as the application of Geographic Information Systems (GIS) and is used to determine land cover types, the amount and distribution of tree cover and potential planting space.

2.3.1 Canopy cover assessment

Viewed from above, the proportion of the city occupied by tree crowns is referred to as the canopy cover. Canopy cover is expressed as a percentage and measures the fractional projected area of tree canopy cover above ground level (Jim, 1989; Walton, Nowak & Greenfield, 2008) and the extent and variation of the vegetation (public and privately owned) across the city (Nowak et al., 1996) as a fundamental measure of urban forest structure (Nowak, 1994). It provides basic structural data which is used to model urban forest functions such as air pollution mitigation and carbon sequestration (Nowak, 1994; Nowak et al., 1996) and determines ecologic functioning (Zipperer et al., 1997), as well as the benefits the urban forest provides (Dwyer et al., 1992; Nowak & Dwyer, 2007). As mentioned previously, many of the urban forest ecosystem services are directly related to the number of healthy leaves on a tree. Therefore, tree cover becomes a simple measure of the extent of the urban forest and consequently the magnitude of services provided by the forest (Nowak & Greenfield, 2012).

Quantifying tree canopy cover has been identified as one of the first steps in the management of the urban forest (Escobedo & Nowak, 2009; Nowak et al., 2010; Schwab, 2009). The comparison of aerial photos over time may reveal changing land use and land cover patterns across the city, which provides a baseline for quantifying urban forest change and may also assist in making appropriate urban planning and management decisions (Nowak, 1993).

Multiple methods and technologies are available to determine and assess the urban tree canopy cover and the relevant costs associated with the management of urban forests (Nowak et al., 1996; Maco & McPherson, 2002, 2003). Various sources of imagery and digital classification techniques are available to assess the urban forest canopy cover (Walton et al., 2008). Canopy cover can also be determined using a free software tool called i-Tree Canopy, a tool forming part of the i-Tree software suite from the USDA Forest Service using freely available remote sensing data from Google Maps (USDA Forest Service, 2012).

Canopy cover data provides the crucial data required to determine the costs and expenditures related to planting, establishment, maintenance and management of the urban forest. Once the canopy cover has been quantified, a target canopy cover percentage can be determined and a tree planting strategy can be developed to increase the canopy cover (McPherson et al., 2005; Roy et al., 2012). Canopy cover data in conjunction with gathering data at ground level such as tree height, stem diameter, species composition and tree health provide opportunities for comprehensive urban forest planning and management (Nowak et al., 1996).

As part of a report on the state of green infrastructure in the Gauteng City Region compiled by the Gauteng City-Region Observatory, a canopy cover assessment was done. The urban forest covered approximately 16.1% of the total area of Johannesburg. The historically wealthy northern suburbs had a canopy cover of 24.2% compared to the canopy cover of 6.7% in the poorer southern quadrant. The report indicated that the new tree plantings could not be identified as part of the canopy cover as these trees were not big enough (Schäffler et al., 2013).

According to Schäffler and Swilling (2013), the urban forest of the CoJ is a significant ecological feature that covers a large area of the city and needs to be understood as a valuable asset. There is one fundamental challenge that characterises this asset – the obviously unequal distribution in the extent of tree cover between the north and south of the city. The historically wealthy northern suburbs have noticeably more canopy cover than the poorer southern part of the city (Schäffler & Swilling, 2013). Venter, Shackleton, van Staden, Selomane & Masterson (2020), conducted a South African wide study and deduced that high-income areas where previously advantaged racial groups (i.e. White citizens) reside, have 11.7% greater tree cover than areas with predominantly Black African, Indian, and Coloured residents.

2.3.2 Inventories

The importance of having an inventory has been recognised for many years. As far back as 1978, tree inventories were seen to be the backbone of a city's urban forest management operations and one of the primary components of structured management programmes (Olig & Miller, 1997).

Tree surveys have been widely used by urban foresters and researchers to collect objective and quantitative data on trees and their growth environment (Alvarez, Velasco, Barbin, Lima & Do Couto, 2005; Jim, 2008). The tree survey process (counting trees and gathering information on each tree) is referred to as a tree census (Peper et al., 2007; Jim, 2008). The data are collected in a systematic study, as the variables required to assess the structure of the urban forest are referred to as the tree inventory (Roman, Battles & McBride, 2014b; Roman, Scharenbroch, Östberg, Mueller, Henning, Koeser, Sanders, Betz & Jordan, 2017). A tree inventory is the collection of tree census data in relation to a specific geographic area at single-tree level and the systematic study of the location and its current condition (size, age, damage, pests, diseases, etc.) (Sun & Bassuk, 1991; City of San Francisco, 2013; Nielsen, Östberg & Delshammar, 2014). A tree inventory can include publicly owned trees such as street trees, trees in parks and other trees on municipal properties, but to be complete should include privately owned trees as well (Keller & Konijnendijk, 2012; City of San Francisco, 2013).

Cozad et al. (2005) explain that a tree inventory analysis provides information on the structure (species composition, diversity, age, distribution and condition of the trees in the urban forest), function (extent of environmental and aesthetic benefits provided by the trees), monetary value and management needs (sustainability, pruning, planting and infrastructure conflict mitigation) of the urban forest resource. A comprehensive inventory provides an essential basis to understand the urban forest as a diverse urban resource and is a broad base of complete data that can be used to not only manage the urban forest effectively, but to develop criteria and performance indicators by which to measure urban forest management (Dwyer et al., 2000; Kenney et al., 2011). A comprehensive inventory is the ultimate answer to collecting data on the urban forest and provides a starting point for the development of predictive models, to estimate the benefits and value of the urban forest. The data can also be used to develop performance indicators that enable measurement of progress towards the achievement of the key objectives for each criterion, which in turn permits the ongoing evaluation of success in implementing the city's urban forest strategy (Kenney et al., 2011). It can be used to identify shortcomings in the structure, use and management of the urban forest and provides information required to implement water and air quality programmes and monitor the rates of change, extent and the health of the urban forest (Dwyer et al., 2000).

Effective urban forestry relies on comprehensive urban tree inventories and which is needed to determine the requirements of a tree management programme. An inventory typically identifies the condition of the trees and indicates which trees require pruning, maintenance, replacement or removal. Areas with an insufficient number of trees as well as additional planting sites in the city can also be identified (Wood, 1999; McPherson, Berry & Van Doorn, 2018). Tree inventories make it possible to project budgets for urban forestry management including routine tree maintenance work (McPherson et al., 2018).

Inventories are useful to inform and educate the public as to the need for, and benefits of, well-managed trees to prevent vandalism. They can also be used to gather public support for a forestry programme. Information on tree species, value, hazard potential, planting priority, canopy cover and density may all be extracted from an inventory and shared with the public (Smiley & Baker, 1988).

Data for the inventory is collected in either one of two methods. A complete survey includes all the trees in a demarcated area in the survey and a sample survey includes only a preselected number of trees in a specified area (Wood, 1999). Even though complete inventories provide the most accurate and useful information about the urban forest (Smiley & Baker, 1988), it is often not feasible due to the extent of the survey and limited funding and resources (Sun & Bassuk, 1991). In that case sample surveys are sufficient to provide a practical and affordable method of establishing a database and inventory of urban forest tree information. The information collected per tree remains the same; it is only the number of trees that is different (Jaenson, Bassuk, Schwager & Headley, 1992; Alvarez et al., 2005).

Kenney et al. (2011) indicate that the setting of criteria and performance indicators alone does not guarantee successful sustainable urban forest management and the involvement and commitment of the community is equally important. According to Cozad et al. (2005), the community can successfully be used as volunteers to collect urban forest data during an urban forest survey. The use of volunteers offers potential for cost savings when inventorying thousands of municipal trees with a low budget. However, the ability of volunteers to collect reliable data is questionable and Cozad et al. (2005) state that the accuracy of data collected by volunteers is relative to the training they receive and the organisation and support of the project management team.

Nielsen et al. (2014) identify a range of comprehensive inventory tools and processes (mainly used in North America and Europe) to complete tree inventories. Field surveys are identified as the most used method to collect data and include ground scanning or digital photography applying tools such as i-Tree. i-Tree has been used successfully to complete tree inventories in the following countries and cities: Chicago, US (McPherson, Nowak, & Rowntree, 1994), Washington DC, US (Nowak, 2006), Philadelphia, San Francisco and New York, US (Nowak, Hoehn, Crane, Stevens & Walton, 2007), Los Angeles, California, US (McPherson et al., 2008; McPherson et al., 2011), Lisbon, Portugal (Soares et al., 2011), Auburn University, Alabama, US (Martin, Chappelka, Keever & Loewenstein, 2011), Minneapolis, Minnesota, US (Cozad et al., 2005), Halifax, Canada (Steenberg et al., 2013) and Dallas, Texas, US (Texas Trees Foundation, 2015).

i-Tree is a state-of-the-art, peer-reviewed software suite developed by the United States Forest Service that provides urban and community forestry analysis and benefit assessment tools. It is a relevant and an internationally recognised process used worldwide (USDA Forest Service, 2012). There was no urban forestry inventory for the CoJ (Buff, 2017) or else in South Africa or Africa available on the web. JCPZ started to compile an inventory for the trees planted during the GSTP project, but it is incomplete and only includes the number of trees and locations from the project.

2.3.3 Single-tree valuation

The basis for assessing the value of any asset or commodity relates to its monetary value. It is difficult to place a value on an asset such as a tree as it is not only the replacement cost at stake, but a range of factors are involved to determine the value of a specific tree (Helliwell, 2008). This monetary value of the tree could be used for the purpose of insurance, compensation and litigation and trees should be recognised as an infrastructure asset of the city, implying that trees (as assets) warrant the expenditure of resources such as labour, energy and maintenance (Moore, 2009). This renders trees important, placing them on an equal basis within the environment with regard to planning calculations and budgeting alongside other assets of known value (Marx, 2005).

A range of tree valuation models or tree-appraisal processes are available and used to determine the value and condition of an individual tree as part of the urban forest. They are all based on an organised approach and depend on the collection of data involving tree-specific and tree location information (Marx, 2005). Some of these tree valuation systems are discussed below:

2.3.3.1 Burnley method

This method was developed in 1988 at the Victorian College of Agriculture and Horticulture Limited, Burnlee Campus, and is used mainly in Australia to value trees. With this method, trees are recognised as financial assets (Moore, 2009, as cited in Watson, 2002).

2.3.3.2 Helliwell system for the visual amenity valuation of trees

The Helliwell system was developed in 1967 and has been widely used in the United Kingdom as well as countries such as Belgium, Slovenia, Ireland, Australia and in the USA to assess the monetary value of trees based on the environmental contribution made by an individual tree to the environment (Helliwel, 2014). This valuation method requires knowledge of trees and uses a point scale to enable the appraiser to assign an amenity value to a tree or a group of trees (Helliwel, 2008, 2014).

2.3.3.3 Capital Asset Value for Amenity Trees (CAVAT)

This tool is used for valuing amenity trees in local municipalities across the UK. It comprises two methods and the "full method" provides a replacement value for single trees or a group of trees that can be used as compensation when trees are damaged, and the "quick method" determines the value of a population of trees as an asset and is used as a strategic tool for management purposes (Neilan, 2010; Doick, Neilan, Jones, Allison, McDermott, Tipping & Haw, 2018). It uses tree measurement at breast height, a conversion formula, tree planting and maintenance costs as its basis to determine the replacement value of trees (Ozdemiroglu, Corbelli, Grieve, Gianferrara & Phang, 2013; Doick et al., 2018).

2.3.3.4 "Guide for Plant Appraisal", 9th edition, by the Council of Tree and Landscape Appraisers (CTLA)

This method has been widely used since 1951 and is based on a measurement of the cross-section of a tree trunk, and a mathematical equation is used to determine the monetary value of the tree (Watson, 2002). The stem circumference of the tree at breast height is measured and used to determine the size of the tree and a tree replacement value is determined by sourcing tree values from retail garden centres (Cullen, 2007).

2.3.3.5 South African Tree Appraisal Method (SATAM)

SATAM was developed in South Africa and was tested and formulated to determine the monetary value of a tree. SATAM is applicable to trees in urban areas and follows a step-by-step process of investigation and data collection about the tree (tree species/origin and condition appraisal) and its position in the landscape and environment (environmental contribution and amenity appraisal). The data is used to reach a reasonable conclusion regarding the value of the tree and includes a small risk assessment section (Marx, 2005).

2.3.4 Tree risk assessment

Tree risk can be defined as the exposure of property or persons to the possibility of injury or damage due to the presence of a hazard or dangerous incident caused by a tree (Ellison, 2005). Tree features such as deadwood, shedding and split branches, or decay that result in damage and eventually tree failure cause hazardous conditions (Ellison, 2005; National Tree Safety Group, 2011). An important aspect of tree management includes the valuation of the possibility of not only a tree causing harm to property or people, but also disrupting activities and services and this should be prevented (Stewart et al., 2013).

Managing tree safety and hazards has been identified as the responsibility of the landowners on which trees grow (National Tree Safety Group, 2011) and depends largely on the tree policy stance and institutional attitudes (Bellows, 2008). Therefore, the implementation of tree risk assessment is advised to assess the possibility of tree failure and the harm that might be caused in the event of a branch breaking or the tree falling prior to it damaging property or persons (Stewart et al., 2013). Unfortunately, aspects such as root decay that is not visible limit the success of tree risk assessments (Smiley et al., 2012).

Subsequent to a tree risk assessment, action is required involving a range of preventative mitigation actions to reduce risk to an acceptable level or remedial action (arboricultural practices such as pruning dead, decaying and damaged branches or installing structural support systems to limit structural damage) to improve conditions for the tree (Smiley et al., 2012). Tree risk incidents have been reported in public media in South Africa. Storms cause trees to fail and fall, causing damage to property, people and the environment (News24, 2018; TimesLive, 2018), but the literature review identified no scientific research concerning tree risk in urban forests.

2.4 Climate change and carbon sequestration

2.4.1 Climate change

The earth's atmosphere consists of gases that trap the sun's heat, and acts as a thermal blanket, creating a natural warming called the greenhouse effect, which makes our life on the earth possible. Certain gases in the atmosphere block heat from escaping and cause an increase in the average temperature on earth. These gases are inter alia methane (CH_4) and nitrous oxide (N_2O) and form part of what is known as GHGs (Intergovernmental Panel on Climate Change (IPCC), 2014). Carbon dioxide (also known as a GHG) is released into the atmosphere through natural processes such as volcano eruptions and vegetation respiration and through human activities such as the burning of fossil fuels, and land use changes such as deforestation (NASA, 2018). Population growth and industrial activity have led to an accumulation of anthropogenic GHGs in the atmosphere (IPCC, 2014).

Climate change can be defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (United Nations, 1992). Climate change has been recognised worldwide as an unprecedented challenge. All ecosystems will be affected by the increases in global air temperatures, increases in atmospheric CO_2 concentrations, change in the rainfall patterns, change in amounts of annual precipitation, more frequent storms and changes in the frequency and severity of wildfires (IPCC, 2007).

To continue reducing GHG emissions and to mitigate global warming, various carbon capture technologies have been proposed to reduce CO_2 emissions (Wang, Liu, Ko & Lin, 2015). The IPCC defines mitigation as the human intervention to reduce the sources or causes of the changes in the climate such as reducing emissions or enhancing the sinks of GHGs (IPCC, 2007).

The South African government has expressed a firm commitment to the multilateral process under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. South Africa is a signatory to both the UNFCCC and the Protocol. Being a signatory to the UNFCCC, South Africa has a general commitment to "implement … measures to mitigate climate change" (United Nations, 1992). Climate change action and emission reductions as well as adaptation for trees are even more important since the Paris agreement in 2015 (Mwakasonda & Winkler, 2005).

Globally, the urban human population has expanded rapidly over the last few decades, with over half of the people on earth living in towns and cities and this phenomenon is accompanied by high rates of rural land conversion into urban areas (United Nations, 2012). This trend of urbanisation is anticipated to continue, highlighting the need to understand and quantify ecosystem service provision within cities. Ecosystem services are increasingly acknowledged as being essential in helping to confront the environmental challenges experienced in cities (Tobias, 2013).

2.4.2 Urban forests and climate change

Urban forests are important in the reduction of atmospheric CO_2. While trees are actively growing, they use more CO_2 through photosynthesis than what they release through respiration, resulting in a reduction of CO_2 in the atmosphere. The cooling effect of trees planted around buildings results in a reduction in the demand for heating and air conditioning, which reduces emissions associated with the production of electricity. In contrast, CO_2 is released by operations and equipment such as vehicles and chainsaws, used to maintain the urban forest, and when trees eventually die, the CO_2 that has accumulated in their woody biomass is released into the atmosphere through decomposition (McPherson, Xiao & Aguaron, 2013).

Because publicly owned urban trees are managed by the city and easily assessed by tree assessors and researchers, the carbon assimilated by these trees can fundamentally be determined and quantified as mitigation action against climate change (McHale et al., 2007). McPherson and Simpson (1999) developed a model for 'Carbon Dioxide Reduction Through Urban Forestry' which consists of a series of calculations that predict total monetary costs, total carbon storage and reduced energy-related carbon emissions over a 40-year period.

2.4.3 Carbon storage and sequestration

During photosynthesis, atmospheric CO_2 is absorbed through stomata on tree leaf surfaces and when combined with water, in a chemical reaction in the presence of sunlight, is converted into mainly cellulose and starch, which are mostly fixed as wood. This storage of the CO_2 in the tree occurs above and below ground in the stems, branches and roots. Carbon sequestration refers to the annual rate of carbon storage (McPherson, 1998) and is measured as the annual rate of storage of CO_2 in above- and below-ground biomass over the course of one year (McPherson & Simpson, 1999). Carbon stock is referred to as the stored carbon in one place at one time (California Climate Action Registry, 2008).

Trees and urban forests act as carbon sinks, fixing carbon through the process of photosynthesis (Nowak & Crane, 2002; Stoffberg et al., 2010). A carbon sink is defined as a mechanism that removes carbon dioxide (greenhouse gas) from the atmosphere (Stoffberg et al., 2010). As trees grow, they accumulate woody biomass over time and therefore CO_2 storage accumulates over time and is proportional to the biomass of the individual tree and the number of trees in the urban forest (McPherson, 1994). Trees make up more than 95% of the urban vegetation carbon sink (Davies, Edmondson, Heinemeyer, Leake & Gaston, 2011). Most urban tree carbon estimates rely on allometric equations obtained empirically through fieldwork or from literature to convert survey measurements of tree size to biomass (Davies, Dallimer, Edmondson, Leake & Gaston, 2013).

Carbon storage within soils and vegetation is one of the ecosystem services that has become a feature of climate change mitigation (Grimm, Faeth, Golubiewski, Redman, Wu, Bai & Briggs, 2008). The Kyoto Protocol recognises trees as a carbon sink and a valid means to offset GHG emissions and meet internationally agreed emissions targets (Grace & Basso 2012). While obviously less in magnitude when compared with carbon emissions per unit area, the size of urban carbon reservoirs nevertheless appears to be substantial (Nowak & Crane, 2002). In order to achieve measurable reductions in CO_2 emissions, assessments of carbon stocks need to be available and urban forest management and policies can be promoted as tools to manage the achievement of this objective (Escobedo et al., 2011).

2.4.3.1 Estimation of carbon stocks and value

In order to estimate carbon sequestration benefits it is necessary to calculate the quantities of carbon that have been or may potentially be sequestered by future growth of the trees and to transpose the sequestered carbon into monetary values. The commercial monetary price of carbon dioxide provides a related value for carbon sequestered in urban trees (Stoffberg et al., 2010). To model carbon sequestration, adequate quantification and reporting of locally quantified carbon stocks are required (Shackleton & Scholes, 2011).

2.4.3.2 Partitioning of stored CO_2

Birdsey (1992) subdivides the stored CO_2 in a typical forest tree into approximately 51% in the trunk, 30% in the branches and stems and only 3% in foliage. Uncertainty prevails in the estimation of biomass and CO_2 stored by root systems. Hendrick and Pregitzer (1993) estimate CO_2 storage of 15-20% in the root system, Jo and McPherson (1995) and Nowak and Crane (2002) estimate around 25% and Johnson and Gerhold (2003) estimate between 16 and 41%. Stoffberg (2006) divided the stored carbon in the Tshwane carbon study according to the root:shoot ratio of 0.78 for root biomass and 45% carbon content of the above-ground biomass and 42% carbon content of the root biomass, as determined by Scholes and Walker (1993).

2.4.3.3 Biomass calculation

The amount of CO_2 stored at any one time by trees in an urban forest is proportional to their biomass and influenced by the amount of existing canopy cover and the tree density

(McPherson, 1994). To measure above-ground biomass, destructively sampling and physically weighing an entire tree is the ideal method (Ketterings, Coe, Van Noordwijk, Ambagau & Palm, 2001). Destructive sampling involves cutting down an entire tree, weighing all the above-ground parts, quantifying the relative amounts of stem, wood and branches and defining the dry biomasses of all the components (Tanhuanpää, Kankare, Setälä, Yli-Pelkonen, Vastaranta, Niemi, Raisio & Holopainen, 2017). However, this method of data collection is time consuming (Ketterings et al., 2001), impractical and costly for a large number of tree species in urban environments (McHale, Burke, Lefsky, Peper & McPherson, 2009).

Gwaze and Steward (1990) examined the relationships between tree dimensions (height, diameter and crown diameter) and the dry weight of different tree components with different regression models for different species and deduced that diameter at breast height (DBH) was found to be a good predictor of total biomass. DBH, which is measured at 1.37 m above ground level, is not an ideal measurement to be used for African savannah species as these species tend to branch at a level lower than this height or are multi-stemmed by nature and a measurement at ankle level is more practical (Tietema, 1993). Tietema also determined that the stem basal area of multi-stemmed trees can be obtained by adding individual single-stem basal areas together and when compared with each other, single-stemmed trees and multi-stemmed trees present no significant difference in the regression between stem basal area and weight between these two growth forms. However, McPherson, Van Doorn and Peper (2016) explain that stem measurements for multi-stemmed trees are calculated as the square root of the sum of the squared stem diameters.

Therefore, the alternative to destructive sampling is to measure standing tree volume (McHale et al., 2009) by means of allometry. Allometry is the study of the relative growth of a part of a plant relative to the entire plant. The equations used in biomass prediction of the allometric models typically use measurements of DBH, tree height and crown dimensions to generate above-ground biomass estimates (Peper & McPherson, 1998; Nelson, Mesquita, Pereira, Garcia Aquino de Souza, Teixeira Batista & Bovino, 1999; Ketterings et al., 2001). Allometric biomass models have been constructed and are used to estimate the standing volume of tree biomass for a wide variety of tree species (Tanhuanpää et al., 2017) as well as the calculation of carbon sequestration (Peper & McPherson, 1998; McPherson & Simpson, 1999; Nowak & Crane, 2002). These equations are referred to as volumetric equations (McPherson et al., 2016).

Very few allometric biomass regressions exist for southern African tree species and Stoffberg et al. (2010) used a generic equation presented by Shackleton (1997) for South African savannah trees to develop a biomass equation for specific indigenous trees in South Africa:

logb = 2,397 (logc) – 2.441 with $r^2 = 0.94$; $p < 0.00001$; $n = 94$, where b is the biomass (kg) and c the stem circumference (cm) at ground level. The equation requires the stem circumference or stem diameter of the tree in question, which is determined by measuring the stem circumference using a tape measure at 50 mm above ground level or just above the basal swelling. This measurement is referred to as diameter at ground level (DGL).

Carbon sequestration research has been conducted in South Africa concerning street trees in an urban setting. In the City of Tshwane, the 30-year carbon sequestration was estimated and the monetary value of indigenous street trees (*Combretum erythrophyllum, Searsia lancea* and *Searsia pendulina*) as well as the exotic *Jacaranda mimosifolia* street trees in the city was determined (Stoffberg, 2006; Stoffberg et al., 2010). On the KwaZulu-Natal coast the potential of above-ground, below-ground, litter, debris and soil carbon stocks of the rehabilitated vegetation of post-mining reforestation activities were quantified and the rehabilitated indigenous forest was found to exceed the mean carbon storage of the reclaimed *Casurina equisetifolia* plantations (Van Rooyen et al., 2013). Shackleton and Scholes (2011) reported on the total biomass of the central Lowveld area. The biomass was calculated using destructive sampling methods to establish allometric equations for nine indigenous tree species and they concluded that the study provides a useful benchmark of relatively intact systems, against which other estimations can be compared.

The only reference to the valuation of the carbon stock of the urban forest of the CoJ was found in a master’s study conducted in two parks in Soweto (Lembani, 2015). The results confirmed that older trees have larger amounts of carbon storage than younger trees. As mentioned above, a valuation of the carbon stock of the urban forest of the CoJ was also conducted by Schäffler and Swilling (2013).

2.4.4 The carbon economy

The “carbon economy” is a range of international initiatives to promote GHG emission mitigation with the sole purpose to mitigate the predicted widespread and potentially severe impact of climate change (Scholtz & De Villiers, 2011). These initiatives are based on the trade in Certified Emission Reduction credits, more generally referred to as “carbon credits”, which are yielded or produced by qualifying GHG mitigation projects (Scholtz & De Villiers, 2011). The carbon economy stems from the Kyoto Protocol where the Clean Development Mechanism (CDM) was identified as one of the three market-based mechanisms considered to allow industrial countries flexibility in attaining their emissions targets. It allows the transfer of cleaner technologies to developing countries. Carbon sequestration by means of afforestation and reforestation was identified as such a strategy (United Nations, 1998). The CDM is a voluntary, project-based mechanism that was developed under Article 12 of the

Kyoto Protocol with the dual purpose of reducing emissions and contributing to sustainable development in developing countries. These CDM projects provide the opportunity to implement project activities that reduce emissions, in return for carbon credits (Scholtz & De Villiers, 2011; Van der Gaast, Sikkema & Vohrer, 2018).

2.4.4.1 Carbon trading

Economically sensitive methods for reducing atmospheric CO_2 emissions have been proposed and carbon credit trading is seen as such an option (Van der Gaast et al., 2018), and McHale et al. (2007) suggest that urban trees may create potential carbon trading opportunities. A carbon credit is a financial instrument that allows the holder, usually a company that has a high carbon footprint, to emit one ton of carbon dioxide. It is used by industries that cannot feasibly reduce CO_2 emissions to buy credits (each worth one metric ton of CO_2) from industries that have reduced their emissions more than the level required. In theory, the carbon trading market provides an economical approach to industries where it would cost more to reduce their emissions than to buy credits (McHale et al., 2007).

According to Poudyal et al. (2012), the trading of carbon has sparked interest among sellers and buyers as a new urban forest output. They maintain that urban forest credits are more desirable than other types of credits and buyers are willing to pay a higher price for these projects than for other projects in the trading business. They conclude that carbon trading projects could present an opportunity to local governments to become active in the offset markets as revenue can be generated while preserving urban forests and providing a wide range of other benefits to society (Poudyal et al., 2012). Companies can choose to offset their emissions by investing in reforestation or tree planting projects that remove CO_2 from the atmosphere (McHale et al., 2007). Unfortunately, due to risks such as the uncertainty of how long sequestered carbon remains in trees, the trading in emission reduction credits of forestry projects has contributed a relatively small share in the international markets (Van der Gaast et al., 2018).

2.4.4.2 Carbon trading verification

Carbon trading can only be successful if investors can be assured that the projects they invest in are scientifically proven to reduce CO_2 emissions. Therefore, when an urban forestry offset project is used as a carbon trading project, scientific proof is required to validate continual net reduction in CO_2 emissions as a specific consequence of the intervention urban forestry project. Monitoring of the project is essential and continuous audits to measure, report and verify the extent of the urban forestry project provide the scientific data required (Poudyal et al., 2012).

Measurement, reporting and verification (MRV) is internationally known as a series of processes that are used to quantify GHG emission and understand the impact of actions aimed at changing emission levels. It can be used as an auditing instrument that will allow for increased accuracy in carbon credit and trading accounting (Koakutsu, Usui, Watarai & Takagi, 2013).

MRV audits provide buyers of these project carbon offset credits with verifiable and audited certificates of their investments. The MRV audit process is one methodological component that may increase the trust and confidence levels required for long-term carbon offsets within the urban forest context (Koakutsu et al., 2013).

2.4.5 Carbon credits, carbon tax and offset providers in South Africa

South Africa has a carbon-intensive economy as it has an abundance of coal resources and relies on coal-fired electricity across the country. The South African government has committed to target ambitious reductions in GHG emissions by 2025 (Alton, Arndt, Davies, Hartley, Makrelov, Thurlow & Ubogu, 2014). Alton et al. (2014) have concerns relating to the implementation of carbon taxes as this will impose substantial adjustment costs on the economy, including job losses and higher energy prices. A draft Carbon Tax Bill was tabled in 2017 and accepted in 2018 to “provide for the imposition of a tax on the carbon dioxide (CO_2) equivalent of greenhouse gas emissions; and to provide for matters connected therewith” (Republic of South Africa, 2018).

In terms of the Carbon Tax Bill, the price of carbon credits in South Africa is proposed as R120 per ton of CO_2e (carbon dioxide equivalent); however, the tax-free allowances may result in an effective carbon tax rate as low as R6 to R48 per ton CO_2e (Republic of South Africa, 2018). In South Africa, the purchase of carbon credits is currently voluntary. It was expected to be implemented in 2019, but to date has not been implemented (Climate Neutral Group, 2019). Many options are available to purchase carbon credits if the credits are purchased are from legitimate projects (Department of National Treasury, 2014).

The carbon tax proposed for South Africa makes provision for the use of offsets to mitigate the tax liability of GHG emitters with the view that the potential trading system would allow companies to achieve their carbon budgets (Promethium Carbon, 2014). Offset providers implement projects from which the carbon offsets will be generated for use, either internally or sold on the market. Once the offset provider has brought its offsets to the market, the taxpayer (individuals and organisations) can purchase these offsets and surrender them into the cancellation account of the South African Revenue Service (SARS), which will deduct these offsets from the total carbon tax liability of the taxpayer (Promethium Carbon, 2014).

Examples of offset providers in South Africa that certify and trade carbon projects are as follows:

- **Credible Carbon** (http://www.crediblecarbon.com/ Accessed on 6 April 2020). This is a voluntary market carbon registry that certifies and trades Africa carbon projects that make a direct impact on poverty. They facilitate local carbon-saving projects that have developmental benefits through the sale of carbon credits on Credible Carbon. An example is the tree planting project in Mannenburg, Cape Town.

- **Envirotrade** (http://www.envirotrade.net/ Accessed on 6 April 2020). A concerned company that wants to offset their carbon dioxide emissions can purchase *Verified Emission Reduction* (VER) certificates from one of the Envirotrade projects, thereby creating a partnership with forest communities in countries such as Mozambique to build sustainable livelihoods and protect the environment.

- **Earth Patrol** (http://earthpatrol.co.za/ Accessed on 6 April 2020). This organisation provides planning, design and development solutions to achieve world-class best practice in Green Building and sustainable low-impact development with tree planting projects in-low income communities, municipalities and schools and food gardening projects.

- **Climate Neutral Group** (https://climateneutralgroup.co.za/carbon-tax/ Accessed on 6 April 2020). This organisation trades in carbon credits by selling carbon offsets from local carbon offset projects such as Joburg Waste to Energy Project, Reliance compost in Cape Town and Basa Magogo project in townships to reduce coal-burning fire emissions.

- **Food and Trees for Africa** (FTFA) (https://trees.org.za/ Accessed on 6 April 2020). FTFA developed the first South African carbon calculator, using the Global GHG Reporting Protocols and providing high-level carbon footprint estimations. This protocol takes local and national travel, electricity and paper usage of a company into account, estimates their carbon footprint for the year and converts it to the number of trees it will take to sequester the carbon dioxide for these activities. FTFA is involved in tree planting projects across South Africa.

2.5 Allometry and urban tree growth prediction

To calculate the effects of trees on the environment and human well-being and examine relationships between growth and influencing factors such as site conditions, models based on urban tree growth data are used (McPherson et al., 2016). These models are referred to as allometric models and, as mentioned above, refer to the relationship between the different growing parts of a plant. Tree allometry entails the relationship between tree biometric variables, such as DBH, tree height and crown width (Peper & McPherson, 1998; Nelson et al., 1999; Ketterings et al., 2001; McPherson & Kotow, 2013). It is used to assess economic and ecological benefits provided by trees of different sizes (Monteiro, Doick & Handley, 2016) as economic, social and ecological benefits of trees are directly related to their size, as indicated by the tree biometric variables (Stoffberg et al., 2010). It enables urban forest managers to meet desired economic, social and ecological goals (Troxel, Piana, Ashton & Murphy-Dunning, 2013), calculates the carbon sequestration rate of trees (Stoffberg et al., 2010) and is key to predicting tree growth and yield (Peper, McPherson & Mori, 2001a, 2001b). Urban forest managers, landscape architects and planners use the data to select the best tree species for specific growing spaces, thereby reducing future maintenance costs and possible conflicts between trees and infrastructure (McPherson et al., 2016).

Nowak (1994) established that when allometric equations developed for tree species grown in forests are used to determine the biomass of urban trees, the results are overestimated. Therefore, allometric equations must be developed for trees planted in the urban environment (Peper & McPherson, 1998; McPherson & Peper, 2012; Yoon, Park, Lee, Ko, Kim, Son, Lee, Oh, Lee & Son, 2013).

Monteiro et al. (2016) describe how allometric relationships of urban trees are influenced by specific urban environmental and management factors as well as regional climate. These variations in the mean allometric relationships are greater for mature trees than for younger trees.

Quantifying the value of tree services and maximising the health and productivity of trees are directly dependent on information on urban tree growth (McPherson et al., 2016). This has the capability to provide the information that urban forestry managers need to manage the urban forest in a sustainable manner by selecting the correct tree species and applying appropriate management practices for optimum tree growth (McPherson & Peper, 2012). Growth predictions can be used to select the most suitable tree species for a potential planting location (Peper et al., 2001a; Peper, Alzate, McNeil & Hashemi, 2014), and plan for future pruning of these trees and therefore predict the production of waste wood and leaf litter (Peper et al. 2001a). Troxel et al. (2013) explain that growth predictions for young trees would assist urban forest managers in the future management and maintenance needs of these trees to improve their survival rate and the benefits of the tree planting projects. They also maintain that growth predictions could be used for species selection of trees most suited to the environment.

According to McPherson and Peper (2012), there are two general approaches to model tree growth: empirical models and process-based models. Empirical models focus on tree morphology and use field measurements of tree dimensions together with statistical methods to predict diameter, height, crown spread and volume, and numerous models have been developed and adapted for use in different environments and countries. Process-based models focus on tree physiology and describe how assimilation and allocation of constituents, for example carbon, translate into morphological growth such as stem diameter and height (McPherson & Peper, 2012).

Both i-Tree and the Lindenmayer-Systems (L-Systems) are empirical models used in urban forestry. The use of the i-Tree suite for urban forestry analysis and benefits assessment has been discussed in this thesis (USDA Forest Service, 2012). i-Tree Eco can be used to estimate tree growth. Calculations are based on tree size data and the growth rates are adjusted according to the condition of the tree and the percentage crown dieback (Nowak, Hoehn, Crane, Stevens, Walton & Bond, 2008). Tree size data involves measurements such as DBH (to nearest 0.1 cm), tree height, height to crown base, crown height and crown diameter (all measured to nearest 0.5 m) (McPherson, Simpson, Peper, Maco, Xiao & Hoefer, 2003). Numerous studies have been conducted using i-Tree to predict tree growth (Nowak, 1994; Nowak et al., 2008).

The L-Systems are a mathematically based theory describing the complex growth of trees and use biological development to model tree growth. Computer graphics are used to develop realistic visualisation models of long-term tree growth (Prusinkiewicz & Lindenmayer, 1990). Universal tree characteristics such as tree height, crown diameter and shape are used and these characteristics are based on empirically derived growth equations to model the growth predictions (Peper et al., 2001a).

Other empirical models have been developed using the logarithmic and exponential regression model proposed by Peper et al. (2001a) and similar analytical methods are used for i-Tree streets (McPherson & Peper, 2012). Stoffberg, Van Rooyen, Van der Linde and Groeneveld (2008) developed tree height and crown size equations for three street tree species in Tshwane, South Africa, and Semenzato, Cattaneo and Dainese (2011) used a similar logarithmic regression model in developing growth predictions for five Italian urban tree species. Peper et al. (2001a) recommend that allometric equations developed for tree species growing in one region not be used to model growth in another region, due to the difference in environmental conditions. However, they state that the approach used in one region may be transferred to other regions.

Process-based models and hybrid models, based on process-based models, are complex and depend on morphological growth processes and the factors that guide these processes. Many parameters are involved in the morphological process of tree growth and therefore many parameters are required to characterise a specific tree species. These models have been used for growth prediction of fruit trees and in the forestry industry (McPherson & Peper, 2012).

Peper et al. (2014) used models providing best-fit ranges from polynomials (linear to quadratic) to logarithmic and exponential, stating that it is difficult to fit a single model to trees in urban areas due to different management practices and the difference in environmental conditions. Equations integrated with numerical models for tree benefits for urban tree growth have been published by McPherson et al. (2016).

Even though the scientific knowledge of tree growth data is important and has proven to be valuable in the urban forestry industry, McPherson et al. (2016) confirm that knowledge in this area is insufficient.

Stoffberg et al. (2008) identify the need for more detail regarding the way tree species grow as this information could be used to guide the placement and tree spacing in relation to human-made structures. Additional data could also be used to develop more precise growth estimates (Peper et al., 2014). In South Africa, growth rate studies of indigenous trees have been conducted. Growth rates for various indigenous trees were determined in Grahamstown (De Lacy & Shackleton, 2014) and Tshwane, South Africa (Stoffberg et al., 2008; Stoffberg et al., 2009). The literature review reveals that no allometric equations and predictions of tree height and crown size have been developed for indigenous urban forest tree species in Johannesburg, South Africa.

2.6 Species diversity

Species diversity is defined as the number of species and abundance of each species that occur in a particular location, contributing to the ecosystem health of an urban forest (Booth, 2006). A broader diversity of trees in urban forests will provide greater security against environmental changes and unpredictable events such as climate change (Alvey, 2006). According to Sun (1992), biological or genetic diversity is vital in the stability and disease tolerance of any street tree population. Low species diversity could leave the tree population more vulnerable to abiotic and biotic stress environments.

Concerns regarding species diversity of street tree populations are not new. In early arboriculture texts, Solotaroff (1911, cited in Richards, 1983) reported that an experiment with 30 tree species of street trees in Washington, DC, provided only 10 or 12 appropriate street tree varieties for that city. He also observed that the species composition of the street trees of Paris, France, at the same time, included only 11 species that could withstand the unfavourable city conditions.

Worldwide, urban tree species diversity remains a concern. Urban environments create a particularly stressful environment for most trees, causing low diversity of street trees in particular, due to a low survival rate of newly planted trees and the short lifespan of many tree species. Species diversity is of concern where most of the older trees in an urban forest are represented by a few species, calling for greater diversity in replacement plantings and new planting projects (Richards, 1983; Sieghardt, Mursch-Radlgruber, Paoletti, Couenberg, Dimitrakopoulus, Rego, Hatzistathis & Randrup, 2005). The urban forest does not only rely on the public trees such as street and park trees, but also includes privately owned trees. Privately owned trees introduce high species richness to the urban forest (Alvey, 2006).

Conway and Vander Vecht (2015) explain that the selection of trees planted in the urban environment is influenced by the emphasis on planting indigenous trees and the availability of tree species at nurseries and suppliers. Dilley and Wolf (2013) maintain that the specific site aspects such as sun exposure, available space, appearance, the proximity of utilities or other structures, intended use and the species composition of trees already planted in the area determine the selection of trees.

2.6.1 The importance of species diversity

The importance of planting for diversity becomes apparent when pests attacking a single tree species, i.e. dominance of a single species, predisposes the urban forest to potentially devastating effects from pest and disease outbreaks (Santamour, 1990; Sæbø, Benedikz & Randrup, 2003; Raupp, Cumming & Raupp, 2006).

The Dutch elm disease caused by *Ophiostoma ulmi* destroyed millions of elm trees across Europe, North America and south-west and central Asia from 1920 to 1940. A different species *O. novo-ulmi* caused a severe Dutch elm disease outbreak in Britain and other parts of Europe (Netherlands, France and Spain) in the early 1970s and at the same time another species *O. novo-ulmi* subsp *Americana* caused death to the elms in North America (Brasier & Buck, 2001; Subburayalu & Sydnor, 2012). In North America and Canada, the emerald ash borer (*Agrilus planipennis*), an exotic pest from Asia, was first identified in Detroit, Michigan and Windsor, Ontario in 2002 and it attacks several American ash (*Fraxinus)* species. It is estimated that up to 15 million ash trees in urban and forested areas have been killed by this insect (Poland & McCullough, 2006; Subburayalu & Sydnor, 2012). Conway (2016) states that not only the emerald ash borer, but also the Asian long-horned beetle (*Anoplophora glabripennis*) attacking the *Acer* spp. poses a current threat to the urban forest of the city of Toronto in Canada. Evidence of the polyphagous shot hole borer, also known as *Euwallacea fornicatus*, and the fungus (*Fusarium euwallaceae*) that grows in the tunnels made by the borer, was found in the Kwa-Zulu Natal province in South Africa with negative impacts already visible (Paap, De Beer, Migliorini, Nel & Wingfield, 2018). Therefore, diversification of tree species is recommended to create a more sustainable urban forest that cannot be destroyed by a single pathogen or insect pest (Raupp et al., 2006; Conway & Vander Vecht, 2015). This recognises species diversity as a key component of strategic urban forest management (Kenney et al., 2011).

2.6.2 Increasing species diversity

Wang et al. (2015) provide a summary of tree species diversity guidelines ensuring tree species diversity and providing maximum protection against pest outbreaks. They promote the use of the 10:20:30 rule, explained by Santamour (1990) as the principle that no more than 10% of any tree species, 20% of any genus and 30% of any family should be planted to achieve spatial as well as biological diversity. The Simpson's Species Diversity Index (Simpson, 1949; Sun, 1992, Subburayalu & Sydnor, 2012; Anandan, Thomas, Benickson, Chitra, Geethu, Augustine, Mithun, Shiva & Kavipriya, 2014) can be used to determine the measure of species diversity, species richness and an evenness of abundance among the species.

Urban conditions are typically harsh and tree species are subject to stressful conditions such as heat, water stresses and human pressures, which are anticipated to increase with climate change (Roloff, Korn & Gillner, 2009). These conditions are not often optimally suited to indigenous plants (Sjöman, Morgenroth, Sjöman & Sæbo, 2016). However, when planting trees in the urban environment, indigenous species should always receive preference (Kendle & Rose, 2000), as they are adapted to grow in their native environment, but cultivars and exotic species that are not invasive should also be considered as they contribute to species diversity, benefits provided by the urban forest and the canopy cover (Kendle & Rose, 2000; McKinney, 2002; Alvey, 2006).

Oyebade, Popo-ola and Itam (2012) determined the diversity of urban tree species in selected areas of Uyo Metropolis in Nigeria, Africa, concluding that educational and residential areas presented higher species richness than commercial areas. In South Africa, research is available on plant species diversity of biomes and geographical regions, but very little could be found on species diversity in urban environments. A study conducted in Grahamstown determined that the tree density and species richness were significantly different in the more affluent suburbs and poorly represented in the township occupied by the predominantly black community (Cimi & Campbell, 2017). 35 different tree species were found, only two of which (*Jacaranda mimosifolia* (14.4%) and *Grevillea robusta* (11.2%)) were represented by more than 10% of the overall tree population.

2.7 Tree mortality and survival

"The success of urban tree planting initiatives critically depends on tree survival" (Roman et al., 2014b). Variables such as the container packaging, overall condition of the tree prior to panting, the size of the tree planting project, the width of the planting area, the correct tree planting practices (Vogt, Watkins, Mincey, Patterson & Fischer, 2015) such as site preparation and the choice and quality of tree species (Pauleit, 2003) are crucial for the survival and growth of newly planted trees. As is implementing a tree care/maintenance programme during the establishment phase of any tree planting project (Pauleit, 2003; Nowak, Kuroda & Crane, 2004). Gilbertson and Bradshaw (1985) identified the common causes for tree mortality of newly planted trees in Northern England to be related to water and nutrient stress (56%), vandalism (18%), girdling of tree stems (12%), soil compaction (9%) and improper staking and tying techniques (5%). In a study conducted in Baltimore, USA, tree size, tree health, tree species and adjacent land use were identified as the factors significantly affecting tree mortality (Nowak et al., 2004). Lu, Svendsen, Campbell, Greenfeld, Braden, King and Falxa-Raymond (2010) concur that land use areas such as lawn strips on sidewalks in low-vehicular traffic areas and tree species have a significant impact on young tree survival and add that planting specifications, direct tree care and local traffic conditions also affect tree mortality rates.

When the number of newly planted trees exceeds losses from death and removal of the overall number of trees in a city or neighbourhood, the urban forest is increased. However, this increase is constrained by high mortality of immature trees (Roman, McPherson, Scharenbroch & Bartens, 2013) and promoted by high survivorship rates during the first five years after planting, which is referred to as the establishment phase (Miller & Miller, 1991; Roman et al., 2014b; Sherman, Kane, Autio, Harris & Ryan, 2016; Elmes, Rogan, Roman, Williams, Ratick, Nowak & Martin, 2018).

Tree survivorship and mortality rates in cities are analysed and used to improve predicted tree replacement needs (Roman & Scatena, 2011). Studies indicate that trees in different cities grow and survive differently (Roman et al., 2013). Gilbertson and Bradshaw (1990) monitored a new tree planting project in the inner-city area of Liverpool and identified that nearly 39% of these trees died within five years of planting. They related this mostly to poor maintenance and design practices. Roman et al. (2014a) observed high mortality rates (up to 27.1%) for newly planted trees in Oakland California, USA, over a period (2007 - 2011) of their first five years after planting and deduced that small trees are more susceptible to stress, injury, inadequate maintenance and vandalism. Meta-analysis of published street tree survivorship rates indicates that the annual survival rate of street trees in the city of Philadelphia, USA, was 94.9–96.5%, with a corresponding annual mortality rate of 3.5–5.1% (Roman & Scatena, 2011), which is within the range of typical annual street tree mortality (3.5–5.1%) for mature street trees (Roman et al., 2014b).

Pauleit, Jones, Garcia-Martin, Garcia-Valdecantos, Rivière, Vidal-Beaudet, Bodson and Randrup (2002) surveyed tree establishment practices in approximately 100 towns and cities in 17 European countries and reasoned that there is a definite relationship between the level of monetary investment in trees and the amount of vandalism, which is directly related to survival rates of planted trees. In the UK, up to 30% of newly planted trees were reported to be vandalised, whereas in central European cities levels of vandalism were below 5%. Roman et al. (2014b) determined that in suburbs where there is homeownership stability, the tree survival rates are higher than in suburbs with unstable homeownership.

2.7.1 Tree planting specifications and procedures

Sustainability of the urban forest will be improved by adhering to professional standards for tree care (Clark et al., 1997). Good practice principles therefore need to be specified and are required for successful urban tree planting (Pauleit, 2003). A range of literature (mainly from Europe) is available on good site preparation practices and tree planting procedures (Hirons & Percival, 2012; Purcell, 2016) and tree maintenance and care (Dujesiefken, Drenou, Oven & Stobbe, 2005). In Germany, the Netherlands and the UK, good practice standards and regulations have been developed and are available for use to arborists across the world (Pauleit, 2003). These tree planting specifications describe standards and procedures for planting, general maintenance and pruning and are available on the internet, on sites such as the International Society of Arboriculture (Gilman & Urban, 2016) and the USDA Forest Service (Bedker, O'Brien & Mielke, 1995) for use in the industry.

2.7.2 Replacing dead and damaged plants

The canopy cover of an urban forest increases as trees are planted and grow to maturity but tends to decline in neighbourhoods that reach ages of 50 or 60 years (Maco & McPherson, 2002) due to tree mortality and incomplete replacement of dead and damaged trees. However, where policies to increase tree cover and replace dead trees are in place, this reduction may not occur (Conway & Urbani, 2007) and replacement needs can be kept at a minimum. This is crucial to maintain a stable tree population (Richards, 1979).

Studies on tree replacement needs and programmes link the need to replace trees with tree survival rates, species longevity, poor tree development such as heavy branches and poorly formed crotches, and vandalism (Richards, 1979). Urban foresters should invest in identifying and evaluating untested replacement tree species that present traits such as adaptability and longevity in stressful urban sites and use these as replacements for dead and damaged trees. This will contribute to improved species diversify and also to long-term sustainability (Raupp et al., 2006).

2.7.3 Tree maintenance and care

Trees in production nurseries grow in optimum conditions as the soil and environment are constantly managed. In contrast, trees growing in urban areas have to deal with climate extremes, disturbed and compacted soils as well as an unpredictable abundance of people, making urban areas among the most challenging environments for trees to survive (Clark & Kjelgren, 1989). Therefore, the survival of trees in urban environments depends on appropriate maintenance practices (Pincetl, 2010; Roman et al., 2014b; Roman, Walker, Martineau, Muffly, MacQueen & Harri, 2015; Vogt, Hauer & Fischer, 2015; Conway, 2016; Moskell, Bassuk, Allred & MacRae, 2016; Widney, Fischer & Vogt, 2016). A healthy tree in good condition can contribute to society in a sustainable manner and minimise potential conflicts with urban infrastructure (Johnston & Hirons, 2014).

In a study conducted in 504 small towns in the USA, Lewis and Boulahanis (2008) found that towns with the highest levels of tree maintenance were directly linked to whether the mayor of the town rated tree benefits and maintenance as important. The study also linked the success of the urban forest to an organisational structure, dedicated personnel and a budget dedicated to tree planting and maintenance. Tree care or maintenance practices in urban settings, also referred to as arboriculture practices (Dujesiefken et al., 2005), include pruning (Kuhns & Reiter, 2007; Badrulhisham & Othman, 2016), mulching, stump removal and fertilizing (Lewis & Boulahanis, 2008), crown stabilisation and wound treatment to prevent pest and disease infestation (Dujesiefken et al., 2005). General urban forestry tree maintenance practices also include watering trees at planting time and at selected periods thereafter to relieve water stress in the trees (Lewis & Boulahanis, 2008; Ferrini & Fini, 2011).

Pruning strategies will influence the successful survival of the tree (Vogt, Hauer & Fischer, 2015). For pruning to be successful, there must be a valid reason for the pruning operations and an understanding of the effect that the pruning will have on the tree. Pruning must be carried out at the proper time, applying proper techniques and utilising the correct tools

(Sellmer, Cotrone, McGann & Nuss, 2004). Pruning is a process of removing dead, broken and diseased branches or occasionally roots from a tree or other plant, using approved practices to achieve a specified objective (Badrulhisham & Othman, 2016). Trees that have been pruned properly will maintain their health and will also contribute to a safe urban environment and enhance the aesthetic value of the area (Badrulhisham & Othman, 2016). No literature could be found on tree survival, mortality rates, tree maintenance and care or pruning of street and park trees, the effect of tree maintenance and pruning on any publicly owned trees in urban forests in South Africa or in the urban forest of the CoJ.

2.8 Land use and land cover

Nowak et al. (1996) identify the surrounding natural environment and land use as the two central factors affecting the amount of tree cover of an urban forest. Land use is the purpose for which humans use the particular piece of land, such as functional/residential uses or economic/commercial uses (Cadenasso, Pickett & Schwarz, 2007; Ganasri & Dwarakish, 2015), also referred to as the function of the land (Dennis, Barlow, Cavan, Cook, Gilchrist, Handley, James, Thompson, Tzoulas, Wheater & Lindley, 2018). Different land uses provide different types of spaces and set limits on the shape and structure of the tree cover. The type, intensity and quality of the land use determine the availability of spaces to plant trees as well as the characteristic distribution, coverage, canopy configuration and composition of the urban forest (Jim, 1989).

Each land use type has characteristics that determine the potential space available for tree planting and growth. According to McPherson et al. (2011) and Nowak et al. (1996), park and residential land uses are known to typically have the highest number of potential planting sites as well as the highest percentage tree cover among land uses. Land uses such as commercial and industrial as a rule provide fewer opportunities to develop green spaces as their structure often limits the potential space available for trees (Nowak et al., 1996) and therefore they have the lowest planting space and subsequent tree canopy cover (McPherson et al., 2011). McPherson et al. (2011) confirm that there is a strong relationship in urban environments between tree canopy cover and land use.

Land cover refers to the physical characteristics or the natural/human-made elements covering the surface of the land. Natural elements comprise vegetation (maintained lawn or vegetative groundcover), soil or water, and human-made elements include paving, tar roads, buildings and other structures (Cadenasso et al., 2007; Ganasri & Dwarakish, 2015), also referred to as landform (Dennis et al., 2018). The terms ‘land use’ and ‘land cover’ are often used interchangeably, even though they have different meanings (Ganasri & Dwarakish, 2015). Van Bommel, Heitköning, Epema, Ringrose, Bonyongo and Veenendaal (2006) refer to green vegetation and urban green spaces as green land cover areas (Noor, Abdullah, Ambagau & Palm, 2013) and they include parks, sidewalks covered in lawn and flowerbeds in this land cover class. Green land cover areas in urban environments introduce nature to the predominantly human-made environment and are an important aspect of urban planning, sustainable development and environmental conservation in a city (Noor et al., 2013).

Land use and land cover are permanently changed by urbanisation and affect the structure, pattern and function of ecosystems in the city environment, which leads to concerns about how these changes influence the daily life of all the residents living in these changed land uses. The effect of the land use and land cover change on the sustainability of "quality of life" for future generations is also a concern (McPherson et al., 2011). Ecologists have been conducting research on the effect of the changes in land use and land cover. Land use classifications have been used to quantify changes in the extent of tree canopy cover by different land use types (Cadenasso et al., 2007). Anderson, Hardy, Roach and Witmer (1976) developed a two-tier hierarchical classification structure that was accepted and used in research. It consists of the urban or built-up land as level 1, which is divided into residential, commercial, industrial, transportation, communications and utilities, industrial and commercial complexes, mixed urban or built-up land and other urban or built-up land. Cadenasso et al. (2007) contradict this and maintain that the urban environment land use is not homogeneous and one-dimensional but heterogeneous.

Researchers tend to use different land use and land cover classes or categories in their research, depending on the local conditions of the urban research sites. Jim (1989) used 12 land use categories: commercial, commercial-residential, residential high-density, residential medium-density, residential low-density, residential government estates, residential temporary, government-institutional, parks and open space, industrial and storage, vacant land and greenbelt. Iverson and Cook (2000) identified 15 urban land uses in their study: residential, manufacturing, transportation, railroad, airport, street, private services, institutional services, military, entertainment, public buildings, warehousing, hotels, parking lots and public open space. They also identified four rural land uses: cemetery, mining, vacant land/agriculture/forests and water. These can also be present in an urban environment. They also used several land cover categories such as forestland, scattered trees with herbaceous groundcover, manicured grassland, non-manicured grassland, impervious surfaces and water. McPherson et al. (2011) originally identified nine land use classes, which were combined into six classes in their study: low-density residential, medium/high density residential, industrial, commercial, institutional and unknown. Dobbs, Kendal and Nitschke

(2013) completed a study on the effect of land use on urban forestry and used only five land use classes: residential, institutional, commercial, parks and transportation.

It is important for urban planners to take cognisance of the distribution of land use and land cover changes to plan for future implications of these activities in the urban environment (Ganasri & Dwarakish, 2015; Zhang, Wang, Hao, Zhang & Hu, 2017). The literature search revealed no research on the effect of land use and land cover on urban forestry in South Africa.

2.9 Urban forestry governance

2.9.1 Governance of the urban forest in general

The term 'governance' differs from the term 'government': governance includes partners such as communities, businesses and non-profit organisations (Pincetl, 2010; Lawrence, Johnston, Konijnendijk & De Vreese, 2011). As urban forestry is a multi-level, multi-stakeholder and multi-disciplinary field, urban forest governance links to this multi-disciplinary framework involving a range of stakeholders, state and non-state organisations (Lawrence et al., 2013). Urban forestry governance should always be context-dependent, and governance arrangements need to be adapted to local conditions and local stakeholders (Konijnendijk van den Bosch, 2014). To be successful, urban forestry governance relies on a diverse body of legislation and policies and requires integration between sectors such as cities and countries, which calls for partnerships with different stakeholders (Lawrence et al., 2011). Konijnendijk van den Bosch (2014) provides a summarised definition of governance as "any efforts to coordinate human actions towards goals". These efforts are typically strategic and are the setting, application and enforcement of generally agreed to rules.

Successful urban forestry governance also depends on stakeholder engagement to improve the quality and acceptance of decisions and create ownership of the urban asset (Lawrence et al., 2011). Different approaches to stakeholder engagement are required as the governance and social context relating to different projects are diverse. A range of methods and techniques to involve stakeholders in urban forest planning, design and management was developed in Vlaandere and has been successful but is dependent on involving all stakeholders from the start of the project and on a range of platforms. These platforms include stakeholder communication with the public of different age and interest groups, at different events, meetings, workshops and individual interviews (Van Herzele, Collins & Heyens, 2005).

Financial support is imperative to create and maintain urban forests. Technical knowledge on aspects such as tree species composition, tree planting and ensuring a high survival rate of the trees in the urban forest is required for sustainable urban forestry management (Lawrence et al. 2011; Lawrence & Dandy, 2012; Lawrence et al., 2013). Urban forestry policies guide delivery mechanisms such as income generation, incentive schemes to improve urban greening and risk management (Lawrence et al., 2013). Monitoring and evaluating all aspects of the urban forest provides evidence through which the management of the urban forest can be consolidated and improved (Lawrence & Dandy, 2012).

In African cities, urban forestry planning and implementation reveal and reflect components of colonial and post-colonial governance (Myers, 2016), where trees were planted to articulate the cultural ideas of colonialists (Jones & Cloke, 2002; Myers, 2016). Research in some African cities focuses on institutional barriers to green infrastructure development and suggests transformations required to make any progress toward the greening of cities across the continent (Ajewole, 2008; Kitha & Lyth, 2011; Fetene & Worku, 2013; Chishaleshale et al., 2015). Ajewole (2008) found that in Nigeria urban greening efforts are uncoordinated due to a lack of legal control and governance. The urban forest approach in Addis Ababa (Ethiopia) is not in accordance with modern forest management practices and excludes the various stakeholders in the management of the forest (Fetene & Worku, 2013). Adaptive governance is required in poorly resourced urban areas such as Mombasa, Kenya, requiring efforts directed towards green infrastructure as opposed to grey infrastructure development, allowing for the implementation of climate change response strategies, currently neglected (Kitha & Lyth, 2011). Across West Africa, urban forest governance has been found to be weak and ineffective (Fuwape & Onyekwelu, 2011). Yao et al. (2019) confirm that the importance of governance in large-scale urban forest projects and the limited experience within management departments of these types of projects warrant more studies on this topic.

2.9.2 Governance of the urban forest in South Africa

The Constitution of the Republic of South Africa of 1996 is regarded as the supreme law of this land as it dictates to the government how to regulate the South African population in a fair and humane way by creating and enforcing legislation that is just and equitable. Chapter 2 of the Constitution contains the Bill of Rights which defines inter alia environmental rights as a right to an environment that is not harmful to the health or well-being of the people of the country. Local government is responsible for creating a safe and healthy environment where its citizens can live and work (Republic of South Africa, 1996).

To meet its constitutional obligation to take reasonable legislative measures to give effect to environmental rights, the government promulgated several environmental and related laws. The Water Services Act 108 of 1997 promotes effective water resource management and conservation. It is therefore important to promote the planning of indigenous and other drought-resistant plants to ensure the optimum use of water resources (Republic of South

Africa, 1997). The National Forest Act 84 of 1998 makes provision for a particular tree or group of trees belonging to a particular species on any land to be declared as a protected tree/s as well as champion trees and to be maintained as such. It does contain a section on community forestry but does not refer to urban forestry (Republic of South Africa, 1998b).

Section 2 of the National Environmental Management Act 107 of 1998 sets out principles for consideration prior to the implementation of tree planting projects, such as the avoidance of the disturbance of ecosystems, the loss of biological diversity and prioritising the needs of people. Section 24 stipulates that the potential impact of any activities on the environment, socio-economic conditions and cultural heritage must be considered, investigated and assessed, prior to implementation (Republic of South Africa, 1998a).

Under section 29 of the Conservation of Agriculture Resources Act 43 of 1983, regulations stipulate invader plant categories and regulate the propagation, cultivation and planting of these plants. Many of them are trees used in the urban forest. Category 1 plants are declared weeds and may not occur on any land. Category 2 plants are declared invaders and may be cultivated and planted under controlled circumstances and category 3 plants are declared invaders that were already in existence at the time of enforcement of these regulations and may be retained, but may not be propagated or planted (Republic of South Africa, 1983).

In addition to the national Acts and regulations, several national and local government policies and strategies refer to tree provision and management and these need to be considered when planning and managing trees within a city context (Galant, 2014).

An internet search produced policies from South African city councils referring to trees. The City of Cape Town has published a Tree Management Policy with the core focus on the management of trees growing on council-owned land in the city. It deals with the conditions for growing, planting, replacing, pruning and removing trees as well as general maintenance of trees. It also deals with creating awareness among the residents of the importance of trees in the city, selecting champion trees and protecting historically significant trees. Tree asset mapping and valuation are also included (City of Cape Town, 2014).

The council of Overstrand approved an Urban Tree Policy in 2017. This policy provides a framework for the management of public trees and consists of guidelines for planting, replacing, pruning and removing trees as well as general maintenance of trees. Damage to trees, trees causing problems and the protection of trees on private property are also included (Overstrand Municipality, 2017). Similar tree management policies of the Drakenstein Municipality (2009), Langeberg Municipality (2015) and Mogale City (2017) were found.

A draft tree management policy of the CoJ refers to the trees in the city as an urban forest and an invaluable asset. The policy provides commitment and strategic direction for the procurement, propagation, planting, maintenance, protection and management of the urban forest. It also provides for the establishment of a valuation system for the urban forest and tree verification and census at determined times, and refers to required research and partnerships to promote the value of trees in the urban context (JCPZ, n.d.). These policies all promote the planting of trees in the towns and cities through the implementation of sustainable tree planting programmes. The literature review revealed no studies on urban forestry governance of trees in cities in South Africa.

2.10 Urban forestry management

Urban forests share their space with people and infrastructure such as roads and buildings (Dwyer et al., 2003) and are confronted with a unique set of challenges, including pests and diseases, air pollution, the effects of climate change, competition from invasive plants and lack of adequate management and planning. They must also grow in spaces where the soil is compacted, on impervious surfaces and with insufficient growing spaces and a lack of essential soil nutrients (Nowak et al., 2010).

Therefore, urban forests are different from rural forests and must be managed differently as they are diverse, connected and dynamic and require a comprehensive approach to their management as the land use types and ownership, urban populations and tree species are all so diverse (Dwyer et al., 2003). Comprehensive urban forest management involves all the trees in an urban area and the associated green space as well as community values, and focuses on proactive management of the urban forest (Nowak et al., 2010). It also considers the connection of activities that affect the urban forest, such as land use and residential development, to take a more holistic approach to management (Dwyer et al., 2003).

The costs of managing urban forests are substantial; however, the overall benefits of urban forests can offset the cost involved in the planning, construction and maintenance or overall management costs. Appropriate and comprehensive urban forest management will reduce costs and enhance benefits (Nowak et al., 2010).

Municipal governments/local authorities are generally responsible for the management of publicly owned trees (Salbitano et al., 2016). A survey of urban tree management in New Zealand found that many local authorities were experiencing difficulties with the management of their tree resources. Severe financial constraints and a lack of baseline urban forest data was constraining the development of meaningful strategies and tree programmes. This was augmented by an overall lack of resources and public as well as political support with conflicting priorities (Stobbart & Johnston, 2012).

Dwyer et al. (2003) insist that to manage a sustainable urban forest, municipal governments should not only maintain the urban forest structure and protect the health of the individual trees, but also involve the surrounding community in the process.

2.10.1 Urban forestry policies

Urban forestry management policies provide broad insight into urban forestry practice, outlining the main objectives, goals and principles for management of urban forests. They include a variety of urban forest strategies, regulations, programmes and plans to assist individual cities in the management of the urban forest (Gudurić et al., 2011; Steenberg et al., 2013). According to Ottitsch and Krott (2005), an urban forestry policy is the bargaining process for the regulation of conflicts related to interests in the utilisation and protection of forests and trees according to urban forestry programmes.

An urban forestry policy, also referred to as a tree policy, is intended to provide a uniform approach to the management of trees on public land within a specific city or town (Galant, 2014; Drakenstein Municipality, 2009). These policies contain standards, guidelines and recommended practices that help a city to protect, maintain and manage the city's urban forest and green infrastructure (Braverman, 2008). They take the regulatory frameworks of the country into account to give credence to the policy and describe the roles of players and stakeholders (Galant, 2014).

The urban forest policy-making process relies on communication between private interests, public agencies, advocacy groups and judicial organisations, as well as a range of resource professionals, including academic and professional experiences. Successful policies are formulated by establishing close links with all the stakeholders and existing municipal policies and should be grounded on scientific research (Janse & Konijnendijk, 2007).

Conway and Urbani (2007) completed a study in Toronto, Canada, which identified numerous different types of urban tree policies. They determined that the variation was due to the size of the municipality. It is assumed that larger municipalities have more resources for services, including an urban forestry programme.

Belgium (Flanders), Denmark, Ireland, The Netherlands and Great Britain have developed and implemented urban forestry policies. The involvement of the urban population is prioritised in all these documents, but funding and political struggles are identified as problematic in the development and implementation of these policies (Konijnendijk, 2003).

2.10.2 Urban forestry management plans (UFMPs)

Management plans are developed to assist urban forest managers in the proactive planning of the urban forest and to establish future directions for management efforts. The purpose of an UFMP is to offer a community vision that inspires action; provides goals, action steps and policies that help translate the vision into physical change; addresses long-term considerations into short-term actions; and finally presents the "big picture", relating the management objectives to the community (Berke et al., 2006). A good plan is an important resource for city managers, documents agreement of the goals created through a community involvement process and serves as a reference for public officials and residents (Berke et al., 2006).

Clark et al. (1997) developed a model for the management of sustainable urban forests to address the interdisciplinary nature of urban forest management and the importance of proactive management and community involvement when managing the urban tree resource. The model was founded on three components, each with specific criteria and indicators for sustainability. The components are resource management, a community framework and the vegetation resource as the engine that drives the urban forest. Today, these criteria and indicators alone no longer inform urban forest management plans and programmes. Kenney et al. (2011) used the three components proposed by Clark et al. (1997) as a foundation and developed updated criteria and indicators for each of these components as a basis for a long-term strategic UFMP. Driving the updating of the criteria and indicators was the statement from Kenney et al. (2011) that too often the need to increase the urban forest canopy cover is used as the sole driver of urban forest management programmes. Canopy cover does not provide an indication of the species diversity of the forest, or the condition of forest resources, or the tree age, size and risk factor distribution of the urban forest. Canopy cover measurements also do not provide an estimate of the carrying capacity of specific locations where it will not be feasible to improve the canopy cover due to a high proportion of hard surfaces. They conclude that factors that render canopy cover estimates unreliable are mortality rates, climate change, invasive insect and disease pests, tree growth habits, land tenure and the availability of funding. These aspects were all incorporated in the criteria and indicators proposed by Kenney et al. (2011) and can serve as a nucleus around which a long-term strategic UFMP can be designed and used as a communications tool to explain challenges to politicians, management and the public.

Modern urban forest management differs from the traditional management principles involving only the technical expertise of a few municipal workers in caring for the forest. A variety of stakeholders are involved, including public participation, and the provision of benefits to the community are some of the key factors in managing the urban forest. Modern urban forest management is based on principles that define not only administrative and technical approaches to management such as comprehensive inventories, specific goals and targets, but also a philosophical approach. Modern urban forest management requires appropriate documentation, referred to as an urban forestry management plan. A UFMP is an official municipal document approved by a city council and contains the defining strategic documents behind operational urban forest management. It is used to translate the goals and objectives into action and provides accountability for all the stakeholders. UFMPs are used worldwide to justify the existence of an urban forest programme, including budgeting and staffing purposes (Ordóñez & Duinker, 2013).

Nowak et al. (2010) write that the first step in developing a sound management plan is to assess the current composition and distribution of the trees in the urban forest. It is important to note that a sound UFMP depends on measurable objectives and data. A city cannot manage any objectives effectively if these objectives are not measured (Cozad et al., 2005).

Each urban forest has a unique set of constantly evolving economic, social and environmental conditions, which determine that a unique UFMP must be developed for each individual urban forest. Miller (1997) developed an urban forest planning model which includes four components: (i) the inventory, (ii) the creation of management goals and objectives, (iii) a management plan, and (iv) a monitoring system for evaluating progress towards goals. This model is still useful today and applied in the development of most UFMPs (Salbitano et al., 2016). Salbitano et al. (2016) describe the development of UFMPs in five steps, very similar to those of Miller (1997). These steps are illustrated in Figure 2.1 and explained below.

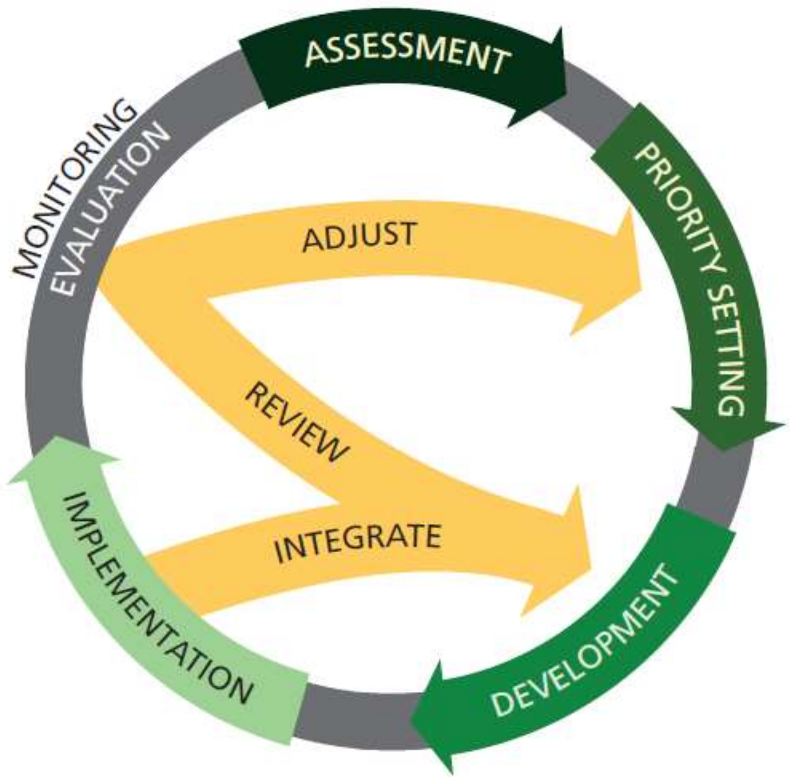


Figure 2.1: Development steps of a UFMP (Salbitano et al., 2016)

2.10.2.1 Steps in developing a UFMP

The first step in the development of a UFMP is to assess the existing urban forest, utilising a variety of data sources including tree species, size, location and condition or tree health at a minimum. The collection of additional data, such as the possible risk or conflicts with structures, presence of pests, management history as well as nearby water resources, is advised (Miller, 1997; Gibbons, 2014; Salbitano et al., 2016). This assessment, referred to as a tree inventory, is essentially the foundation of urban forest management and provides the basis for efficient management of the forest (Gibbons, 2014). It can also be used to locate valuable trees, such as heritage trees (Van Wassenaer, Schaeffer & Kenney, 2000). Conducting an inventory should come before the development of goals and a management plan, as it is critical to first understand the resource before developing a plan of action (Gibbons, 2014).

The second step involves identifying the scope and needs for the development and maintenance of the urban forest, setting goals and priorities for the future of the resource. Data from the urban forest inventory will identify potential concerns and future management needs, establishing the basis for a priority-setting process with goals and action steps to deal with the concerns, improve the urban forest resource and identify the potential for the production of goods and ecosystem services (Salbitano et al., 2016).

The third step is the development of the management plan (Salbitano et al., 2016). Urban forests are diverse in composition, local land uses and community values, and therefore a one-size-fits-all approach to management planning is not effective. Individual UFMPs should be compiled for each individual urban forest with locally specific strategies that meet the needs of that urban forest's residents (Dwyer et al., 2003). Therefore, management plans for urban forests vary in scale (e.g. local, city, national or regional), duration (short term to long term) and type (e.g. master or strategic). Their development requires adequate baseline data, professional guidance, time, funding and the collaboration of multiple stakeholders (Salbitano et al., 2016).

According to the model of urban forest sustainability developed by Clark et al. (1997), a comprehensive management plan should address three main components of an urban forest: the vegetation resource, the community framework and the resource management approach. Goals, strategies, objectives and action steps should be linked to these themes and will provide the detail for implementation of the plan (Gibbons, 2014).

Van Wassenaer, Satel, Kenney and Ursic (2012) recommend that the goals and action steps of the vegetation resource of any UFMP be addressed in five themes. The tree inventory theme relates to timelines for updating inventories and ensuring that inventory data remains up to date and in a usable format, such as a GIS. The tree establishment theme includes tree planting priorities, species distribution, tree replacement policies and suitable planting locations. The tree maintenance theme includes pruning standards and cycles, maintenance specifications and tree risk inspection cycles. The tree protection theme relates to tree protection standards and heritage tree protection. The last theme, the stewardship initiative theme, includes goals related to public-private partnerships, community tree care programmes, or alien invasive species removal and the use of indigenous plants (Kenney et al., 2011). Dwyer et al. (2002) and Salbitano et al. (2016) insist that the success of sustainable urban forest management depends on the support and participation of the local community and the involvement of the community in the decision-making processes from an early stage. Goals and action steps should include public communication and education (Dwyer et al., 2000) and the development of community partnerships to help build community awareness and involve more community members in developing and maintaining the urban forest (Van Wassenaer et al., 2012; Kenney et al., 2011).

The model by Clark et al. (1997) proposes a resource management component which includes actual management components required for successful urban forestry management. There are three substantive themes related to the resource management approach: budget, municipal coordination and management, and tree risk management. Adequate funding is critical for the implementation success of any UFMP and should be explicitly discussed within the UFMP (Gibbons, 2014). Most of the goals and objectives presented in a UFMP should be connected to the budget in some way. The goals should address short- and long-term funding as well as future urban forest programme funding (Van Wassenaer et al., 2012). Municipal coordination and management is a critical component and includes any goals or objectives required to improve the management of the urban forest. Goals involving staffing education, improving legal aspects of local tree management, developing resident participation forums or interdepartmental cooperation structures should be included (Clark et al. 1997). Goals and objectives within the tree risk management section include the need for tree risk assessment and inventories, risk mitigation strategies and specific goals related to risk-prone species and planting locations (Van Wassenaer et al., 2012), together with risk abatement recommendations (Kenney et al., 2011).

The fourth step is the implementation of the management plan and relies on detailed work plans for the implementation and maintenance objectives, with clearly delineated responsibilities, specified actions and responsible people or departments (Salbitano et al., 2016). The implementation approach will vary depending on the nature of the local government, administrative system and laws, the stage of development of the urban environment and the level of public involvement. Typically, however, it will include aspects such as clarifying the roles and responsibilities of the entities managing the urban forest, providing regulations and policies, providing the necessary financial resources, outsourcing certain functions, hiring tree-care professionals, developing public education and engagement programmes and conducting activities according to the detailed work plan (Salbitano et al., 2016).

Monitoring and valuation is the last step in the development of a management plan for the urban forest (Salbitano et al., 2016) and should be written before the UFMP is implemented to align the plan with the baseline data collected during the assessment phase, providing information on the effectiveness of actions implemented through the plan (Gibbons, 2014). Ensuring the sustainability of urban forests requires a long-term monitoring programme to evaluate the effects of management interventions and the achievement of management objectives and generates information to adapt and inform future management plans (Salbitano et al., 2016).

Dwyer et al. (2003) and Gibbons (2014) concur that the urban forest is dynamic and requires an adaptive approach to its management, constantly reassessing and updating the plan to address changes. This will provide flexibility and the continual valuation of the success of management actions towards achieving goals. An adaptive management approach includes monitoring the effectiveness of the programme, identifying areas for improvement and modifying these to address shortcomings (Dwyer et al., 2003).

2.10.2.2 Types of management plans

Urban forestry management planning documentation varies in title from management plans to master plans to strategic plans. The purpose of all urban forestry management planning documentation is to provide guidance for the sustainable management of the urban forest and contains a range of strategic and operational information (Gibbons, 2014).

Strategic plans

The urban forest as an important city resource deserves management strategies, commonly defined as high-level plans with a long-term goal, ensuring the success of the resource (Millward & Sabir, 2010) and aiming to attain urban forest sustainability (Van Wassenaer et al., 2012). A strategic plan or framework is usually a 20-year strategy consisting of individual management plans (usually 5-years) to form the link between the high-level plans and the on-the-ground management activities (Van Wassenaer et al., 2012). It addresses the importance of community involvement in planning for the future of the urban forest (Gibbons, 2014).

Master plans

Like the other plan types, the description of a master plan varies. It is not as all-inclusive as a strategic plan, but includes goals and objectives, such as plans for street tree planting and maintenance, or budgets (Gibbons, 2014). Master plans are common across the US (Miller, 1997). For example, the master plan of the City of Tulsa, in the state of Oklahoma, developed by public and private stakeholders, included all public and private trees managed and cared for by all the different stakeholders within the city limits and provided overall goals with specific, measurable objectives, strategies and action items for actions required in the urban forest (City of Tulsa, n.d.).

Management plans

Following the strategic framework by Van Wassenaer et al. (2012), a management plan is an individual five-year plan. Every five years a management plan must be developed to provide the actions required to reach the vision set out in the high-level strategic plan. A management plan is a type of operational plan that connects the strategic priorities with daily management activities (Gibbons, 2014). A study in Canada indicated that in the development and adoption of UFMPs, deciding on the most effective level for sustainable management and involving public participation on a neighbourhood scale is critical (Steenberg et al., 2013). Most UFMPs deal with trees on public land only (Conway & Urbani, 2007).

Operational plans

Operational plans usually describe one task, such as pruning or tree planting, and contain for example pruning schedules and operational practices. Other examples may include maintenance plans, risk management, or damage response plans (Gibbons, 2014).

Ordóñez and Duinker (2013) analysed 14 UFMPs found in Canada and identified the themes, criteria and indicators most used in approaches to urban forest management. They deduced that the environmental/ecological themes of maintenance, enhancement-establishment and diversity dominate UFMPs and many contain numeric targets linked to maintenance practices such as pruning and tree replacement. This reflects that most municipalities have a lower-than-desired level of maintenance, canopy cover and diversity requiring attention.

Gudurić et al. (2011) compared the status, planning and management of the urban forest in Belgrade, Serbia with the city of Freiburg, Germany and identified problems in terms of the development of UFMPs in Belgrade. Evaluation of management policies by various interest groups and experts in Belgrade confirms the value of incorporating the public in the decision-making process of urban forestry matters and illustrates methods to involve residents in the management of the urban forest (Lakicevic et al., 2014). Except for the research by Fuwape and Onyekwelu (2011) already mentioned, the literature search revealed no other research on urban forestry management from Africa.

Shackleton (2006) writes that in South Africa the planning and management of urban forests are the responsibility of local authorities, which are underfunded and lack expertise for appropriate planning. The lack of research to provide knowledge and models for workable urban forestry policies and strategies results in fragmented and uncoordinated urban forestry management in South Africa, which focuses on short-term tree planting and maintenance.

In a study conducted in South Africa in 28 local municipalities, Chishaleshale et al. (2015) determined that most of these local municipalities (in the Eastern Cape and Limpopo provinces) do not manage their urban green space in a planned, systematic or integrated manner, which is potentially a consequence of a lack of political will, support and funding. Indications are that poor governance of urban forests at national and local government levels in South Africa and the lack of dedicated funding can negatively influence the potential benefits to residents and the environment (Chishaleshale, 2012).

2.11 Tree planting in the urban forest

The importance of trees and the urban forest in the city environment has been identified, described, and internationally acknowledged (Simpson & McPherson, 1998). Nowak (2012) determined that a mixture of natural and managerial factors influence tree planting and natural regeneration in cities. Natural regeneration of invasive species will have a substantial influence on species composition and tree cover in cities in the future. Without tree planting and management, the urban forest composition could shift to mostly invasive tree species in the future.

The overall vision for any urban forest includes the improvement and maintenance of the canopy cover by planting more trees and replacing dead and damaged trees to maintain the canopy cover (Booth, 2006; Nowak, 2012), and protecting the urban forest investment of the city (Millward & Sabir, 2010). Expanding the urban forest through tree planting projects is considered to be a cost-effective means of mitigating the urban heat island effect and associated expenditures for reducing temperature in buildings (Simpson & McPherson, 1998) and reducing atmospheric CO_2 (McHale et al., 2007).

However, inappropriate tree selection or incorrect placement of trees can result in potential injuries to residents due to tree failure or cause allergies due to excessive pollen or can even introduce invasive pests that can eradicate other tree species. These incorrect choices are all cost related and, if coupled with the input costs of planting trees and the ongoing maintenance costs involving the use of specialised equipment and burning of fossil fuels, may overshadow the benefits of urban trees in some cases (Nowak & Dwyer, 2007; Lyytimäki et al., 2008). Therefore, careful tree planting and management plans are essential to achieve the maximum benefits of trees.

2.11.1 Tree planting programmes or projects

Summit and Sommer (1998) and McPherson and Young (2010) are confident that urban tree planting programmes have great potential to increase the numbers of trees planted in cities and suburbs. These programmes are being implemented in many US cities for their multiple environmental and health benefits, as discussed previously (Bolund & Hunhamaar, 1999; Tyrväinen et al., 2005; McPherson et al., 2005; Pincetl, Gillespie, Pataki, Saatchi & Saphores, 2013).

Evidence cautions that urban forestry programmes have the potential to create or exacerbate inequity by planting in areas with higher existing canopy cover and higher income (Donovan & Mills, 2014; Locke & Grove, 2016), but Watkins, Mincey, Vogt and Sweeney (2016) found the opposite to be true where non-profit environmental organisations are involved in tree planting projects as they play an important role in urban tree planting projects (Dwyer et al., 1991).

Kirnbauer et al. (2009) developed a Microsoft Office-based Prototype Decision Support System for sustainable urban tree planting programmes aimed at guiding urban foresters in improving the urban forest canopy. They conclude that the choice of tree species, in conjunction with the choice of planting locations, is the most important of all the contributing aspects.

2.11.1.1 Tree planting location

Urban areas are composed of diverse spaces and environmental conditions, providing varied locations and conditions for plant growth (Clark & Kjelgren, 1989). Identifying potential spaces suitable for tree planting locations in the urban environment is important for expanding the urban forest, as tree placement is a key element in urban landscape architectural design (Wu, Xiao & McPherson, 2008).

When selecting plant locations in urban areas, factors such as climate, soil characteristics (physical and chemical components), environmental conditions (including sufficient light), physical space available above and below ground, existing vegetation, land ownership and legal aspects regulating the land and maintenance requirements (Pauleit, 2003; Bassuk & Trowbridge, 2004; Mullaney et al., 2015) as well as atmospheric pollutants that will affect tree growth (Clark & Kjelgren, 1989) must be considered. Wu et al. (2008) identify criteria for selecting potential planting sites as land uses or land covers that will improve plant growth and include natural cover such as grass and bare soil. They also state that tree placement should be at least 0.6 m from any impervious surfaces and the minimum land cover surface should be 1.5 m^2 for small trees, 3.3 m^2 for medium trees and 9.3 m^2 for large trees and large trees should be given priority, as more benefits are accrued from larger trees.

Methods to locate potential tree planting sites in urban areas are available. The rapid urban site index (RUSI) model is a field-based tool and takes the climate (precipitation, temperature and exposure), urban attributes (traffic, infrastructure and surface), physical characteristics of the soil (texture, structure and water penetration), chemical characteristics of the soil (electrical conductivity, organic matter and pH) and biological characteristics of the soil (estimated root zone, A horizon and wet aggregate stability) into consideration to identify planting locations (Scharenbroch, Carter, Bialecki, Fahey, Scheberl, Catania, Roman, Bassuk, Harper, Werner, Siewert, Miller, Hutyra & Raciti, 2017). Wu et al. (2008) developed a scientific method using GIS and land cover data to create a base map for locating potential tree planting sites. This strategy focuses on the spatial availability of a planting site and combines it with tree sizes to identify the potential tree planting site.

2.11.1.2 Tree species selection

Challenging environmental conditions, coupled with limiting site conditions and impacts from construction works, negatively affect tree growth and limit the choice of tree species best suited to urban environments (Pauleit, 2003). The success of a municipal tree programme relies on selecting the most appropriate trees for the specific planting locations. When the right tree is planted in the right place, it will appreciate in value and will contribute to the view people have of the urban forest; a wrong plant choice will eventually result in death of the tree and will not add to the value of the urban forest (Gerhold & Porter, 2000; Kirkpatrick, Davison & Daniels, 2013).

According to Urban (1992), research suggests that there is no “right tree” for urban areas as many urban sites are not suitable for tree planting and that soil modification and drainage should be adapted to improve the success rate of trees in an urban environment. Clark and Kjelgren (1989) are of the view that only tree species that present tolerance for growing in restricted spaces and unfavourable conditions such as increased temperatures should be used in urban environments. They add that trees with inherently poor branching structure, vigorous rooting system and inedible fruit should be avoided, but trees that are resistant to pests should receive preference.

2.11.1.3 Maintenance of newly planted trees

Maintenance practices are important to ensure the success of tree planting projects (Vogt, Watkins, et al., 2015) to maintain tree vigour and growth, aid in reducing pest problems and add to overall tolerance to environmental stresses (Clark & Kjelgren, 1989). During the establishment and juvenile phases of a tree’s life, adequate maintenance will ensure early survival and establishment in the urban landscape and during the mature phase of the tree’s life, extending the benefits trees provide (Vogt, Hauer & Fischer, 2015).

Maintenance practices, including frequent watering, creating proper soil drainage (Clark & Kjelgren, 1989; Gilman, 2004), correct mulching (Vogt, Watkins et al., 2015), pest management (Clark & Kjelgren, 1989) and pruning positively, impact tree growth rates (Clark & Kjelgren, 1989; Nowak, McBride & Beatty, 1990). The management of the urban forest is the responsibility of local authorities and municipalities. Across the globe tree maintenance funding is limited by the economic principle of scarce resources. Municipal resources (e.g. money, time) must be divided between what are considered essential services (police and fire departments, road and electricity projects, etc.) and non-essential or less essential city services such as urban forestry management and tree care. Therefore, tree maintenance is often removed from municipal budgets (Vogt, Hauser & Fischer, 2015).

2.11.2 Worldwide tree planting programmes and projects

Nine of the 12 largest cities in the US have mayoral tree planting initiatives. These initiatives aim to improve their canopy cover by planting in the region of 20 million trees (McPherson & Young, 2010). Urban forest benefits are improved when the canopy cover of an area is expanded (Simpson & McPherson, 1998) and these benefits have been realised in many US cities through tree planting programmes (Morani Nowak, Hirabayashi & Calfapietra, 2011; Pincetl et al., 2013).

Prominent large-scale tree planting initiatives such as the "Million Trees LA" in Los Angeles and "MillionTreesNYC" in New York City aim to plant one million trees in these cities to increase the environmental benefits from the urban forest (McPherson et al., 2011; Morani et al., 2011). In the Million Trees LA project 94 786 trees were planted between 2006 and 2010 (McPherson, 2014; Pincetl, 2010). In The MillionTreesNYC project a million trees were planted between 1997 and 2015 as part of their urban sustainability plan to create a healthy city (McPhearson et al., 2011). Other cities in the US with goals to plant a million trees are Houston, Salt Lake County, Sacramento and Denver (Young, 2011). In massive tree planting campaigns such as these, it is crucial to plan the initiative with care and pay attention to planting design, site and species selection, tree protection and maintenance to ensure high survival rates and maximise tree benefit (Morani et al., 2011).

McPherson et al. (2011) question if there is room for a million trees in Los Angeles as well as the environmental and other benefits that one million trees would provide. Carmichael and McDonough (2018) assert that planting large numbers of trees should not be the overriding goal of tree planting programmes and that the success of such a programme should not rely solely on the number of planted trees. They contend that the success of tree planting programmes relies on the involvement of the local community in the entire programme.

2.11.3 Tree planting programmes in Africa and South Africa

The Greenpop Foundation is a non-profit organisation involved in tree planting projects and environmental education in countries in sub-Saharan Africa. They have been involved in the Cape Town Urban Greening Programme since 2010 and have planted 15 288 trees in schools, clinics, houses of worship and community organisations on the Cape Flats, up to August 2018 (Greenpop, 2018). In 2014, they collaborated with the South African National Biodiversity Institute (SANBI) to plant 400 fruit trees and indigenous vegetation at the Abalimi Bezekhaya community gardens in Khayelitsha (Green Times, 2018).

In Rwanda, East Africa, a tree planting project of a different nature was implemented by a non-profit organisation as tree planting has symbolic and practical significance. The project has three aims – to create a space for community dialogues and meetings, to represent pillars of peace and to form part of the reconciliation process in the country (The Institute for Justice and Reconciliation, 2015).

Food and Trees for Africa, a section 21 social enterprise in South Africa, reports on their involvement in tree planting programmes together with various partners such as municipalities, schools and private companies. A range of special events has been held such as planting trees to commemorate important people or events such as Earth Day, Arbor Week/Month or World Food Day. They claim to have distributed 4.5 million trees in the country (Food and Trees for Africa, 2018).

The Million Trees Project, an initiative of the Stellenbosch Municipality, was initiated in 2013 with the aim to green the communities of the municipality, reduce poverty and create jobs to create dignified living while reducing their carbon footprint. The website reports that 79 090 trees have been planted since 2013, but the last information on the website reports on a tree planting project in 2014, and therefore up-to-date information on the tree project is not available (Million Trees Project, 2018)

The Millennium Tree Planting programme in Grahamstown, a tree planting project of Rhodes University, promotes tree planting and the Makana Municipality claims to plant approximately 640 trees throughout the municipal area on an annual basis (Gauld, 2015; Makana Municipality, 2016).

The GSTP is the largest tree planting project in Gauteng and the focus of this study. A master's study was conducted in 2015 to calculate above-ground tree biomass and carbon stored by this project. The study was restricted to tree species in Petrus Molefe Park and Thokoza Park in Soweto and did not only include trees planted during the GSTP project, but also included older trees (approximately 30 years old) in the parks (Lembani, 2015).

The literature search revealed no other research on tree planting projects in South Africa and the CoJ.

2.11.4 Tree planting strategy

A tree planting strategy provides a long-term strategic framework to guide sustainable tree planting in a city and provides long-term vision, goals and aims to guide the implementation of the vision (Clark et al., 1997; Booth, 2006; Kenney et al., 2011). Establishing tree planting programmes that will withstand the test of time is a challenge. Governance, political agendas, pressures and public support, coupled with limited resources, may collectively or individually affect sustainable tree planting programmes negatively (McPherson & Young, 2010).

Examples of tree planting strategies available on the internet indicate that these strategies can be specific or general in their vision, aims and goals. An example of a specific strategy is the

Town Street Tree Planting Strategy of the Shoalhaven City Council, New South Wales, Australia. It provides a framework for the methodical and planned planting of street trees throughout the city. An example of a general tree planting strategy is that of the City of London, south-western Ontario, Canada called its strategy the “Plant More, Tree Planting Strategy 2017-2021”. This strategy provides a vision for the urban forest and strategic goals and actions to achieve canopy cover targets across the city, with specific targets for public and privately owned trees over a period of five years. It also includes goals to improve their planting and maintenance operations by implementing and maintaining best practice standards (City of London, 2017). The CoJ does not have a published tree planting strategy or guidelines for tree planting projects but has a draft tree planting policy guiding tree planting in the city (Chokoe, 2017).

Though a number of studies have examined the role of communities in tree planting, the implementation of urban tree planting strategies and the benefits created by these strategies, little research has been conducted on the aspects to be dealt with when compiling a tree planting strategy. In this part of the study scientific literature was reviewed on tree planting in urban environments with the aim to identify aspects that need mention in the development of guidelines for urban tree planting to provide direction and navigate the implementation of the goals of the tree planting policy of the CoJ.

2.12 Structured literature review

In this section the focused literature review deals with a description of the literature, research discourses and tree planning information and includes an overview of the time frames of the publications, the journals publishing the articles and the countries where the research studies took place.

2.12.1 Research discourses and main focus areas of the literature review

The focused literature search identified two research discourses and therefore all the article titles and abstracts were linked to either “tree planting policies and programmes” or “tree growth and survival”. The “tree planting policies and programmes” discourse was discussed in 48 papers and the “tree growth and survival” discourse in 44 papers.

Within these discourses, papers on similar topics were clustered into seven groupings. These specific groupings were benefits, governance, species selection, tree growth and health, tree planting policies and programmes, tree planting specification, and tree survival and mortality. Each of the specific groupings included a range of topics, often overlapping and dealing with a broad base of information. These topics are discussed in the tree planting information section below.

2.12.2 Overview of the time frames, journals and countries of publication

This overview is presented below to give context to the extent of the literature review and indicates when and where papers were published as well as the countries where research was conducted on tree planting.

The papers that met the inclusion criteria were published from 1980 onwards, with only four papers published between 1980 and 1989, and five between 1990 and 1999. Between 2000 and 2009, 13 papers were published. The publication rate increased substantially thereafter, as 70 papers were published between 2010 and 2020. Between 1980 and 2006 there were 17 years in which no papers were published, but from 2007 to date, between one and nine papers were published every year.

The papers were published in 23 different journals*. Urban Forestry and Urban Greening* was the journal with the most publications, with 35% (n = 32) of the papers, followed by *Arboriculture and Urban Forestry* (entitled *Journal of Arboriculture* until 2006) with 22% (n = 20), *Landscape and Urban Planning* with 12% (n = 11), *Cities and the Environment* with 8% (n = 8), *Arboricultural Journal* with 3% (n = 3) and *Urban Ecosystems* with 2% (n = 2). The remaining 17 journals (18%) represented one article each and were found in a variety of journals. Except for the journal *Forests*, the other journals were essentially non-urban forestry journals: *Buildings and the Environment, Chemical Engineering Transactions, Civil Engineers: Municipal Engineer, Environmental Behaviour, Environmental Conservation, Environmental Management, Environmental Pollution, European Journal of Horticulture Science, Geoforum, Geojournal, Geophysical Bulletin, Journal of the American Planning Association, Journal of Urban Affairs, Landscape & Ecology Engineering, Plosone,* and *Restorian Ecology*.

More than half of the journal papers originated from the USA, specifically North America (65%, n = 60) and 11% (n = 10) from Canada. Six papers (6.5%) originated from Europe, Asia and Australia each, and 2 (2.5%) from South Africa. One article originated from Iran and one from South America.

2.12.3 Tree planting information

The tree planting information identified during this focused literature study dealt with improving the survival of the trees. The information is described according to the research discourses and the specific groupings in each discourse. For the sake of structure, the specific groupings are discussed alphabetically.

2.12.3.1 Tree growth and survival discourse

Benefits

McHale et al. (2009) state that some urban tree planting projects in specific locations may be cost-effective investments for reducing the concentrations of GHGs, particularly carbon dioxide, in the atmosphere. McPherson and Rowntree (1993) say that tree planting programmes can potentially conserve energy, save costs, positively influence property value enhancement and avoid stormwater runoff. Benefits of tree planting include energy saving in the form of a reduction in annual air conditioning energy use, cooling and peak load demand (McPherson & Simpson, 2003) However, resource managers can create more effective projects by minimising costs of pruning and programme administration, planting large-stature trees and manipulating a host of other variables that affect energy usage (McPherson & Rowntree, 1993; McHale et al., 2009).

Governance

Quinton, Östberg and Duinker (2020) confirm that tree management and maintenance are important to ensure that benefits are realised and that tree management policies should be customised for this purpose. Urban forest management must keep track of the location, survival and growth of planted trees to efficiently manage and maintain the trees to provide relevant benefits (Vogt & Fischer, 2014).

The governance of large-scale urban forest tree planting projects includes the importance of public participation, proper planning, effective preparation before project initiation (Yao et al., 2019) and addressing persistent inequalities in street tree access across neighbourhoods (Lockwood & Berland, 2019). Tree planting initiatives focus on increasing canopy cover in environmental injustice communities, and the equitable distribution of urban trees is difficult to achieve (Danford, Cheng, Strohbach, Ryan, Nicolson & Warren, 2014). The Federal Urban & Community Forestry Programs (U&CF) programmes in the US are an excellent example of how this may be achieved (Hauer, Johnson & Kilgore, 2011).

The way residents perceive and value the urban forest can have implications for achieving urban forestry goals (Locke, Roman & Murphy-Dunning, 2015) and is essential to prevent and manage social resistance and negative attitudes towards urban trees (Kirkpatrick et al., 2013). Residents can provide input in matters such as the choice of tree species and how to maintain the trees in their area (Carmichael & McDonough, 2018). The community of the City of Oak Ridge, Tennessee, place high importance on planting trees, increasing species richness, planting density, pruning and tree care, and prefer indigenous, pest- and disease-resistant, hazard-free trees and trees with a long lifespan (Jennings, Jean-Philippe, Willcox, Zobel, Poudyal & Simpson, 2016). As such, it is very important to address residents' negative perceptions of trees in the planning of tree planting and to involve communities in tree planting decisions as this can restore confidence in city management (Battaglia, Buckley, Galvin & Grove, 2014). This involvement in tree planting and maintenance projects is motivated by an enjoyment from working with nature as well as a strong social motivation (Austin, 2002).

Stewardship is fundamental for the survival of urban trees found in challenging conditions and for reaching and maintaining canopy cover goals and its anticipated benefits (Breger, Eisenman, Kremer, Roman, Martin & Rogan, 2019). Implementing stewardship programmes can be effective for promoting street tree viability, despite the many human and environmental stresses on urban street trees (Boyce, 2010). However, these programmes depend on knowledge and information provided by the local government to the community (Moskell et al., 2016) and the importance local governments place on ensuring that residents feel valued in maintaining public trees (Carmichael & McDonough, 2018).

<u>Species selection</u>

Effective selection of the tree species for urban tree planting programmes is important to ensure substantial environmental benefits in urban environments (Amini Parsa, Salehi & Yavari, 2020), restore the standing of neighbourhoods and improve the desirability of living in the areas (Merse, Buckley & Boone, 2009). Roy, Davison and Östberg (2017) and Conway and Vander Vecht (2015) show that local government and communities differ in their criteria for species selection as urban forest management selects tree species based on factors such as environmental conditions, visual and aesthetic contributions and statutory regulations. In contrast, communities identify species characteristics, site factors, management costs and maintenance issues as important factors for street tree species selection. This inconsistency leads to the need for the communication of goals and plans (Conway & Vander Vecht, 2015). Roy (2017) adds that street tree species selection should be governed by tree species characteristics, maintenance issues and problems caused by different species.

The lack of technical tree selection criteria for urban areas generates obstacles for infrastructure development and limits the benefits obtained from this resource (Núñez-Florez, Pérez-Gómez & Fernández-Méndez, 2019). A database for the selection of suitable tree species for urban environments is required and should consider site characteristics and natural distribution, tree appearance, ecosystem services, management activities and the risks and interferences caused by urban woody plants as the most important factors to consider when selecting species (Vogt, Gillner, Hofmann, Tharang, Dettmann, Gerstenberg, Schmidt, Gebauer, Van de Riet, Berger & Roloff, 2017). Almas and Conway (2016) maintain that even though exotic tree species are often preferred, selecting indigenous tree species can increase the ecological integrity of tree planting programmes.

Tree planting policies and programmes

Kirnbauer et al. (2009) describe important aspects to be discussed in these policies and programmes and highlight that tree selection, planting location, age distribution and canopy cover are most important for sustainable urban forestry management. Tan, Lau and Ng (2017) add micro-climate to the list. The success of tree planting programmes depends on the degree to which these programmes are integrated in the existing frameworks of city government and infrastructure management, with reference to funding, types of collaborations between non-profit organisations, communities and local government (Pincetl et al., 2013). Planning tree planting initiatives is part of the urban green infrastructure in metropolitan cities in the US and is guided by funding availability, commitment of the political body in charge, stewardship programmes and public awareness (Young, 2011). In contrast, insufficient funds and personnel, lack of equipment and lack of political support in local municipalities in Limpopo and Eastern Cape provinces in South Africa are instrumental in these municipalities not being able to manage tree planting systematically (Chishaleshale et al., 2015).

Municipalities that focus on urban forestry preservation using policies, guidelines, dedicated committees and master plans are positioned better to achieve desired aesthetics, tree density and character of the urban forest (Galenieks, 2017). Cities with a large population appear to spend more on urban trees; likewise, cities with higher income households and lower poverty rates would have higher expenditures on urban tree programmes (Zhang & Zheng, 2012). While municipalities are often constrained to plant trees only on public land, non-profit organisations can use donor money to plant trees on private land, reducing the physical barriers to planting in neighbourhoods that are densely populated (Watkins, Mincey, Vogt & Sweeney, 2016). However, preferences and willingness of the community to pay for urban tree planting and their views on the impacts of the trees in their area vary and should therefore be addressed in policies (Ng, Chau, Powell & Leung, 2015).

Tree planting specification

This grouping contains literature on the development of tree planting priority indices using indicators such as pollution concentration, population density, low canopy cover (Morani et al., 2011) and the size of trees to be planted (Sydnor & Subburayalu, 2011) to motivate decisions to provide trees with the most benefits possible. Tree planting strategies should include specifications from planting to long-term maintenance involving the community from the beginning (Clark & Kjelgren, 1989). Yang and McBride (2003) recommend that tree planting specifications include guidance to choose the right planting technique. Pauleit (2003) confirms this statement and reiterates appropriate tree planting specifications as being essential to the success of projects and their management.

Tree survival and mortality

Survival and mortality of tree planting projects depend on a range of factors, including type of planting stock, production methods such as baled and burlapped or bare rooted trees to provide planting stock (Jack-Scott, et al., 2013), community involvement and resident attitudes (Richardson & Shackleton, 2014; Kirkpatrick, Davidson & Daniels, 2012). Tree survival and mortality also depend on the prevention of vandalism (Richardson & Shackleton, 2014). Roman and Scatena (2011) highlight the importance of setting goals, objectives and action plans to ensure optimum survival rates, tree coverage and related benefits.

2.12.3.2 Tree planting policies and programmes discourse

Benefits

Tree planting projects deliver a range of benefits to communities and these benefits are strengthened by maintenance efforts of volunteers (Thompson, Nowak, Crane & Hunkins, 2004). A complete list of benefits is discussed in section 2.2.1.3 and Table 2.1 of this chapter. Sklar and Ames (1985) found that psychologically, tree plantings allow residents of the community mastery and control over their environment, which positively influences tree survival of a tree planting project.

Governance

Stewardship success and community group dynamics affect urban street tree survival and growth (Jack-Scott et al., 2013). According to Moskell and Allred (2013), residents believe that the responsibility for the stewardship of park trees and street trees lies with local government. As post-planting maintenance of newly planted trees is critical for the survival of trees and for the success of urban tree planting efforts, urban forestry management has to implement efficient maintenance strategies. Mincey and Vogt (2014) consider with regard to maintenance of newly planted trees, a watering strategy is essential for tree health, growth and survival.

Dawes, Adams, Escobedo and Soto (2018) point out that the development of urban forestry initiatives to equitably increase tree cover and improve the governance of urban ecosystems requires understanding of differences in income, education and preferences of the community. However, climate plays a major role in the choice of tree species and it is the responsibility of urban forestry management to guide the community in their plant choices, especially in arid cities (Foley, Wolf, Henriquez, Sandoval & Rogstad, 2019).

Species selection

Leers, Moore and May (2018) debated the assessment of indicators of street tree selection and establishment and found that inappropriate selection and poor-quality stock, poor planting technique, insufficient irrigation, poor weed control and inadequate maintenance can influence successful street tree establishment. Fontaine and Larson (2016) assert that selecting and planting the right tree in the right place ensures that benefits are realised and Deb, Halim, Tuihedur Rahman and Al-Ahmed (2013) state that proper management and objective-specific actions influence street tree growth and survival, but density, diversity, composition and distribution of street trees in the city also contribute. Lanza and Stone (2016) and Fontaine and Larson (2016) report that it is important to do proper research on the tree species that will be best suited in the specific climate and micro-climate zones in an urban environment to ensure tree growth and health and to limit mortality.

Tree growth and health

Discussions on aspects that improve tree growth and health include tree species selection, the location of the planting site, tree maintenance and management factors (Nowak et al., 1990; Blair, Koeser, Knox, Roman, Thetford & Hilbert, 2019), design characteristics of street tree planting systems (Grey, Livesley, Fletcher & Szota, 2018), adding amendments during planting practices and planting larger trees during tree planting projects. These aspects should form part of a tree planting programme (Oldfield, Felson, Auyeung, Crowther, Sonti, Harada, Maynard, Sokol, Ashton, Warren, Hallett & Bradford, 2015).

The effect of nursery production methods and planting techniques can influence plant performance and affect post-plant growth, but growth and health are also affected by the physiological condition of the trees, climate, micro-climate, soil characteristics and tree care (Ferrini, Nicese, Mancuso & Giuntoli, 2000; Harris & Bassuk, 1993).

Tree planting policies and programmes

Pincetl (2010) found that the success of municipal tree planting programmes depends on the coordination of aspects such as organisations responsible for planting, funding, long-term maintenance, residents' needs and acceptance of the trees and the availability of quality trees from nurseries. Koeser, Gilman, Paz and Harchick (2014) add the importance of having decent planting specifications, including maintenance and replacement details to improve tree growth and survival. Community participation and residential support for municipal urban forestry policies are essential to make urban forestry policies come to fruition (Conway & Bang, 2014). According to Limoges, Pham and Apparicio (2018), the age of buildings and land use zones in urban areas and the evaluation and choice of planting sites using a site assessment tool should be considered to improve the success rate of tree planting programmes.

Tree planting specification

Improving overall soil conditions (Scharenbroch, 2009) by adding organic amendments during planting and regular maintenance (McGrath & Henry, 2016; Vidal-Beaudet, Galopin & Grosbellet, 2018) should be included in tree planting specifications. This is in line with Jim (1993), who says that the prevention of soil compaction improves growth, health and overall tree survival and, together with soil condition improvement such as the provision of rooting space required by the tree and the removal of other negatively influencing structures such as cables, lighting structures and paving, should be included in specifications.

Labrosse, Corry and Zheng (2011) associate tree stabilisation or support systems with improved health during the establishment of trees, but incorrect management of the support systems may affect tree damage and overall tree health. This is confirmed by Thacker, Martin and Slater (2018), who caution that preventative measures should be specified to limit damage inflicted by tree support and protective systems on establishing trees. Locating potential tree planting sites in urban environments is important to ensure expected benefits (Wu et al., 2008; Hwang, Wiseman & Thomas, 2015) and Attwell (2000) reports that it is essential to focus on choosing areas lacking vegetation for this purpose.

Tree survival and mortality

Planting the right tree in the right place improves tree survival and growth and limits mortality (Abdullah, Kanniah & Ho, 2018; Ko, Lee, McPherson & Roman, 2015). Specifying transplant timing, planting depth, proper handling, planting techniques and post-planting maintenance techniques (Allen, Harper, Bayer & Brazee, 2017; Vogt, Hauer & Fischer, 2015; Lu et al., 2010) and choosing locations in stable homeownership areas (Roman et al., 2014a, 2014b) also affect tree survival. Abdullah et al. (2018), Koeser, Hauer, Norris and Krouse (2013) and Pauleit et al. (2002) and Miller and Miller (1991) regard the identification of suitable planting locations and species selection as important to prevent the risk of tree fall and to prolong tree life. Vogt, Hauer and Fischer (2015) add that early crown dieback and lower trunk damage are negatively related to tree success. Factors affecting long-term mortality of residential shade trees also include the size of trees at the time of planting (Roman et al., 2014b; Vogt, Hauer & Fischer, 2015). Elmes et al. (2018) and Lu et al. (2010) confirm that young trees have higher mortality than established trees and they promote the planting of larger trees. According to Elmes et al. (2018), juvenile trees planted near newly constructed buildings have increased tree mortality, possibly due to construction soil disturbance.

Smith, Dearborn and Hutyra (2019) report that trees that grow fast die young and they promote the establishment and preservation of tree health as key for the provision of benefits in urban areas. Widney et al. (2016) report that high mortality undercuts the ability of tree planting programmes to provide benefits, thereby placing focus on improved tree survival rate and growth of trees.

Roman et al. (2014a) deduce that the balance of planting and mortality in a street tree population depends on the involvement of communities in tree planting programmes. This is confirmed by Roman et al. (2015) and Lu et al. (2010), who maintain that stewardship and care from the community are important to prevent juvenile tree mortality. The survival of trees is dependent on stewardship and proper planning and maintenance practices. Tree maintenance is of the utmost importance to prevent tree death and high mortality rates (Elmes et al., 2018; Abdullah et al., 2018).

Finally, Martin, Simmons and Ashton (2016) emphasise that survival is not enough: The effects of micro-climate on the growth and health of urban trees are significantly impacted by micro-climate zone and should be considered in species selection and targeted tree care. This focused literature review identified a comprehensive range of academic journal articles between 1980 and March 2020 discussing scientific research aspects of tree planting. The aim was to use the data as a basis for the development of guidelines with recommendations for future tree planting projects in the CoJ.

2.13 Gap in the research

From this literature study, the following gaps were identified that guided the research:

- Very little research has been done on urban forestry in city environments in South Africa.
- Very limited research has been done on urban forestry in the CoJ.
- Very little research has been conducted in South Africa involving tree inventories and no research has been conducted in the CoJ.
- No research has been done in the CoJ to determine the total carbon sequestration value of the trees planted as part of the GSTP project.
- No allometric equations and predictions of tree height and crown size have been developed for indigenous urban forest tree species in the CoJ, South Africa.
- Very little research could be found on tree survival and mortality rates of trees planted in the urban environment in South Africa.

- No research has been done to determine the effect of land use and land cover on the growth and size of trees planted in the CoJ.
- No research could be found on tree maintenance and care or pruning of street and park trees or the effect of tree maintenance and care and pruning on any publicly owned trees in urban forestry in South Africa or in the urban forest of the CoJ.
- No research has been done to determine whether external factors such as tree maintenance, human influence or infrastructure have an effect on the growth of the indigenous trees planted as part of the GSTP project.
- No studies on urban forestry governance and urban forestry management plans in city environments in South Africa could be found. Studies on urban forestry management have been conducted in local governments in the Eastern Cape and Limpopo provinces.
- No research on strategic planning of tree planting projects in South Africa and the CoJ could be found.

2.14 Conclusion

Compared to the ongoing research and wealth of information on the contribution of urban forestry research worldwide, there is limited information on urban forestry research in Africa and South Africa. The literature review revealed limited scientific research and publications available on the urban forest and tree planting programmes of the CoJ. The low profile of this discipline is due to an overall lack of interest in this science in Africa (Shackleton, 2012).

The purpose of this literature review was to provide background information to underpin this research. The aim was to develop a strategic management plan to improve the survival rate of trees planted during tree planting projects. Strategic planning includes guidelines to develop a strategic management plan for new tree planting projects to improve survival rate and optimise the value added to the urban forest of the CoJ. To support the guidelines for new tree planting projects, the study also aimed to determine the influence of land use and land cover and the effect of external factors such as tree maintenance required, human influence, conflict or damage caused by infrastructure and the presence of pests and disease, on the trees planted during the GSTP project. Finally, the interaction between age, stem diameter, tree height and crown dimensions of tree species planted during the project was determined. Data to guide the location, choice of tree species planted, tree planting specification and process of new tree planting for future tree planting projects was based on the information identified in the literature review and the structured literature review.

The overall justification for the study is to improve the canopy cover and value of the urban forest of the CoJ by reducing the mortality rate of trees planted during new tree planting projects and improving the survival rate of these trees, thereby improving the contribution of urban forests to the mitigation of global warming and climate change.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

In this chapter the research approach and methodology applied and followed to achieve the research aim and objectives and answer the research questions of the study are discussed. The methods for study area delineation, sample group composition and data analysis are described. The validity and the reliability of the study as well as the ethical considerations are explained.

3.2 Research design

Research design is the strategy for achieving desired objectives and includes the research approach, instruments, data collection and analysis methods. A quantitative research strategy was applied as it is an objective and systematic process using numerical data to collect information and can successfully be used to describe and test relationships and to examine cause-and-effect relationships (Bacon-Shone, 2020). Observations of a situation as it is, without modifying the situation (Leedy & Ormrod, 2010), aiming to provide a broad overview of a representative sample of a large population (Mouton, 2001), can be conducted by means of quantitative research methodology. Quantitative research was used to generate numerical data from a large sample population of the trees planted during the Greening Soweto project. The data was used to evaluate the tree inventory, calculate tree growth parameters, identify new allometric equations for specific indigenous trees and determine the value of the trees and the effect of site features on tree growth. Quantitative research was also used to identify aspects to be included in the tree planting guidelines.

A literature review (non-empirical study) was conducted (Mouton, 2001), which provided background and guiding information on the overarching topic “urban forestry” and related topics, to provide an overview of historical and existing research and practices of the urban forestry industry. Empirical studies were completed by analysing, assessing and interrogating existing data and using primary data (observation data, field surveys, tree measurement and site feature data etc.) to provide answers to the research problems and objectives of the study. A combination of empirical studies such as evaluation research, methodological studies, field or natural experimental designs (Mouton, 2001) and a structured literature review (Nielsen et al., 2014; Hilbert, Roman, Koeser, Vogt, & Van Doorn, 2019) were implemented.

In order to achieve the research aim and objectives, the research was divided into three separate sections. Subsequent to a comprehensive literature study and this methodology section, the first part of the research involved an analysis of the tree inventory of the Greening Soweto project of the 2010 FIFA World Cup in the CoJ, physical verification by means of tree inventory data and the development of an improved inventory for future use. This evaluation set the scene for the research to follow. The second part of the research involved the determination of the growth of the trees and an evaluation of different growth parameters across the different regions in the city. An attempt was made to develop growth relationships and equations and to determine constant values to be used for the calculation of the carbon sequestered by these trees. During this process, data from the Tshwane carbon study by Stoffberg (2006) was used to supplement the data of this current study. The carbon sequestration and the carbon value of the trees were calculated using existing growth relationship equations developed for indigenous trees in the City of Tshwane. The carbon value was determined for different scenarios as highlighted by the inventory analysis to validate discrepancies. Then the effect of site features such as land use, land cover and external factors such as maintenance requirements, the effect of human influence, infrastructure conflict and pests and diseases on tree growth were determined to identify possible reasons for growth deviations and provide guidance for optimum planting locations to improve the survival rate of future tree planting projects.

The aim of the final part of the research was to develop guidelines with recommendations for new tree planting projects to improve the survival rate of the planted trees and optimise the value added to the urban forest over an extended period. To do this a structured literature review was conducted and is described in the literature review chapter, which provided the baseline information for the tree planting guidelines. Where relevant, new information obtained from the previous parts of the study was added to the literature review results to create a complete and new tree planting guideline for the CoJ.

3.3 Research process defined

Research is a process of systematic investigation, focusing on a particular subject area with the aim of adding to that body of knowledge, and it is carried out in stages (Arthur & Hancock, 2007). Based on the outcome of the literature review and the information provided by JCPZ, the research process was defined and the different stages described.

The first stage of the study entailed an analysis of the verified tree register of the 200 000 trees planted during the Greening Soweto project, as provided by JCPZ. The tree register data was analysed, and the results were used to identify the relevant tree species planted and determine the number of existing trees and the mortality and survival rates of the trees planted during the project. From this information, tree inventory parameters were established and the study sites (locations) for the second part of the research were identified.

The second stage of the research involved a determination and evaluation of the growth of the trees, which relied on inventory data collection. During the tree measurement process, the trees were identified, digital photographs were taken, and site feature and condition data collected. Digital photographs were used to calculate growth parameters of each of the trees using the VolCalc software program, version 1 (Barrett & Brown, 2012) and the data was used to evaluate the growth of the trees relevant to different regions and locations in the city. The tree measurements also provided the data required to model growth prediction for the individual tree species. The tree measurement data from this study was supplemented by tree measurement data from the Tshwane study (Stoffberg, 2006) with the aim to improve the growth prediction model developed for four indigenous tree species in the City of Tshwane and adapt it for use in Gauteng.

The second stage of the study also involved the assessment of the trees and commenced with a determination of the value of the trees. Trees were measured and the results used to calculate the quantity of carbon sequestered by the measured trees and the estimated total standing trees for the project. This was subsequently extrapolated to the carbon sequestration potential over a 30-year period. The monetary value of these trees (standing and projected over a 30-year period) was calculated. These results provide indications of the difference in the value of the existing trees and the value should all the 200 000 trees that were planted have survived by 2017 and what it should or could be 30 years from 2017. The site feature data included the identification of the land use and land cover where the trees were planted, the tree maintenance requirements, the presence of pests and diseases, the presence of infrastructural conflict and the effect of human influence. This data was used to determine the effect of these aspects on the growth (tree stem diameter at ground level (DGL), tree stem circumference at ground level (CGL), stem diameter at breast height (DBH), stem circumference at breast height (CBH), tree height, canopy diameter, stem diameter at first leaf and tree crown volume) of the trees.

The third stage of the study combined these results, together with the growth parameter evaluation results, transcending the knowledge gap, motivating and obtaining data to develop guidelines for new tree planting projects to improve growth and survival rate, management and maintenance of newly planted trees and optimise the value of the urban forest in the CoJ. The development of the guidelines for new tree planting projects in the urban forest is underpinned by a structured literature review, with specific focus on survival of new trees planted as part of tree planting projects and supplemented by new information from the second part of the research study.

3.4 Study area

The research was conducted in the urban forest of the CoJ (26.2041° S and 28.0473° E), in the province of Gauteng, South Africa (Figure 3.1). After modest beginnings as a gold mining town, founded in 1886 (Beavon, 2004), the CoJ is now recognised as a world-class African city and the economic capital of both South and sub-Saharan Africa, covering an area of 2 300 km^2 or 23 000 ha. It is the largest city in South Africa and the provincial capital of Gauteng (Republic of South Africa, 2020). According to the 2011 census, the CoJ has a total population of 4,4 million (4 434 827), the majority of whom are aged between 19 and 39 and a population density of 2 696 persons/km^2 (Joburg, 2018). The city is at 1 753 m above sea level with a highland climate and is situated in the Grassland biome. The mean annual temperature is 16.2 °C and varies from 4 °C to 30 °C. On average, the city receives 537 mm of rain per annum (Department of Environmental Affairs, 2019).

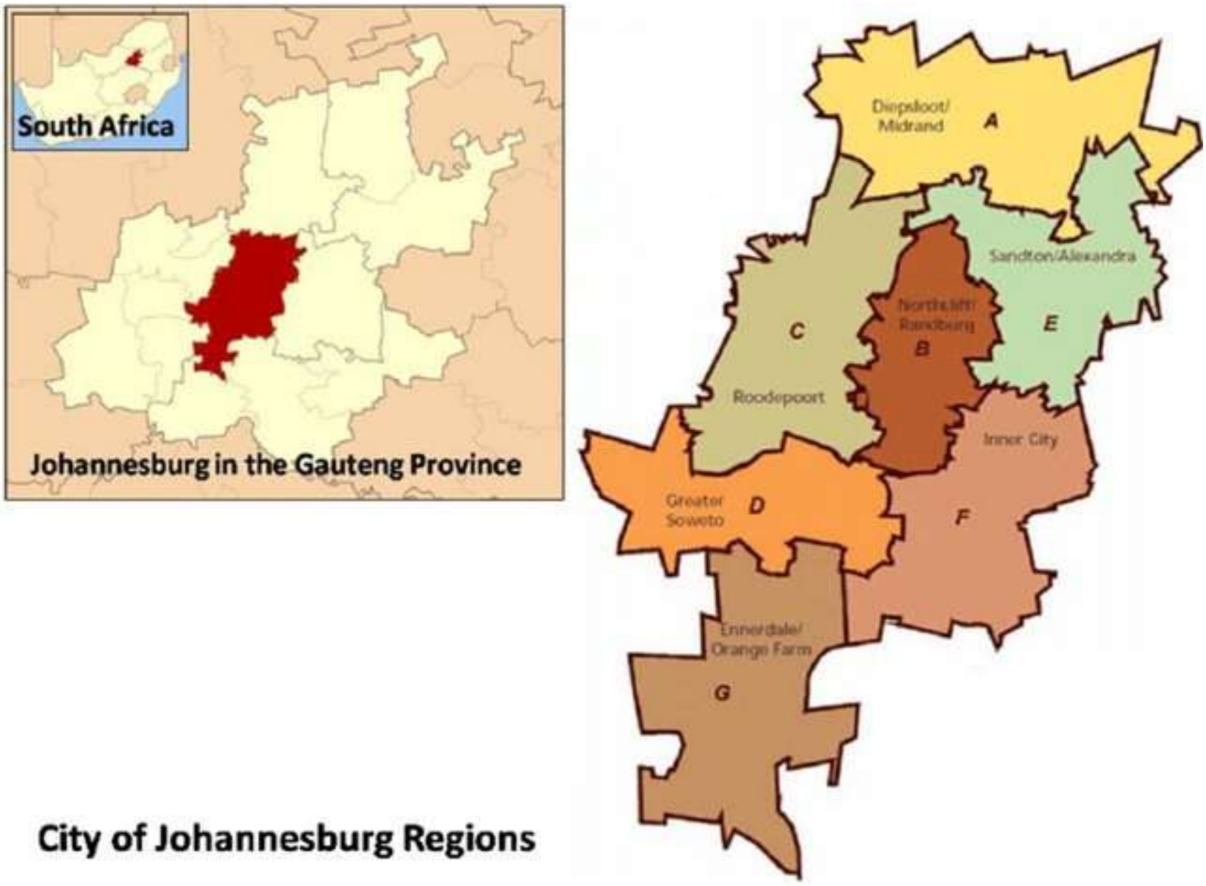


Figure 3.1: City of Johannesburg, Gauteng province, South Africa, with locations of the regions of the city (Nastar & Ramasar, 2012)

The CoJ was segregated by wealth and race before the establishment of the city when the Kruger Republic's Gold Law (1885) banned black ownership and occupation of reserved mining land (Le Roux, 2012). Subsequently in 1904 the city was spatially segregated when attempts were made to move non-white residents to Klipspruit (a township approximately 35 km south-west of the city). People of colour who worked in the city were packed into small houses and shelters in what were referred to as "townships". In the South African context, a township is an underdeveloped racially segregated urban area reserved for non-white residents. The largest township (including Klipspruit) was formed in the south-western quadrant of the city in what was later referred to as Soweto, resulting in residents having to travel long distances to work. Similar but smaller townships were also created: Kathlehong and Vosloorus in the south-eastern section, Alexandra to the east and later Diepsloot to the north of the city (Figure 3.2). When apartheid was legalised in 1948, measures to confine non-whites to the peripheries of the city were instituted and housing was made available in faraway located areas on the peripheries of the cities.

The Group Areas Act of 1950, confining specific racial groups to specific areas, was one of the most noticeable of the past policies implemented by the government to drive spatial segregation (Le Roux, 2012). In essence, the apartheid city is a place where white people had access to all the major facilities provided by local authorities and people of colour lived in a part of the city devoid of these facilities. Another characteristic of an apartheid city is the physical barrier between the "white" areas and the townships. In the case of Soweto there is a freeway and a railway line; in the case of Alexandra there is a freeway (Beavon, 2004).

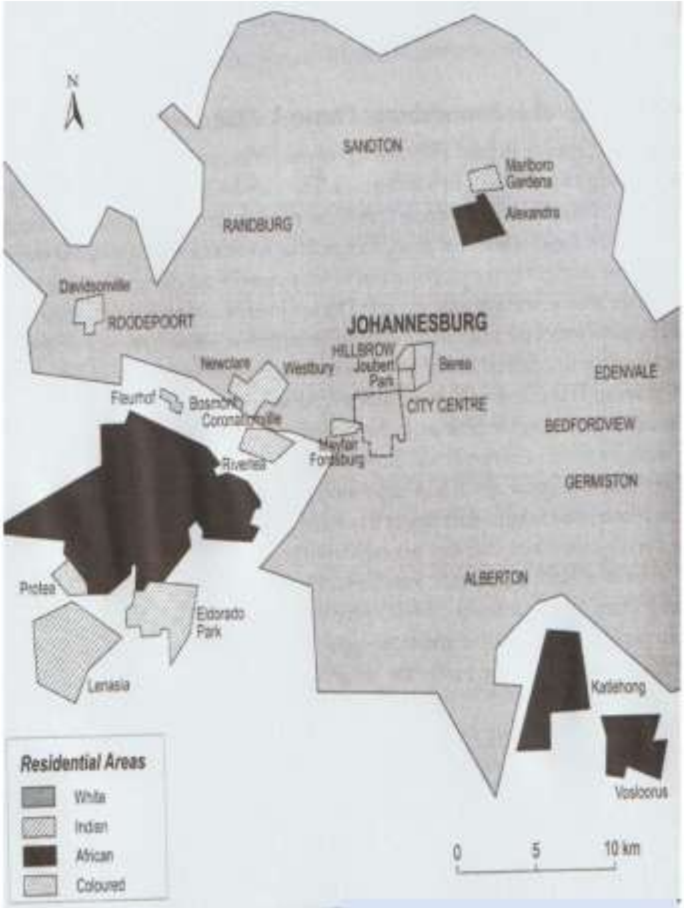


Figure 3.2: Johannesburg during apartheid, identifying white, Indian, African or black and coloured residential areas (Beavon, 2004)

With the end of apartheid, the city's boundaries were extended to include 11 previous local authorities into a new Greater Johannesburg Transitional Metropolitan council in 1995 and changed to the Greater Johannesburg Metropolitan Council in 2000, including another two local authorities. In 2000, the city consisted of nine previously white affluent local authorities and four poorer black authorities (Le Roux, 2012).

The legacy of apartheid is still visible in this post-apartheid era and very prominent in the urban forest of the city. An impressive tree canopy is visible over the Houghton suburb in Region E (Figure 3.3) and the Randburg suburb in Region B (Figure 3.4), whereas the absence of a tree canopy in Soweto, Region D, is apparent (Figure 3.5).

Figure 3.3: Urban forest in Houghton, Region E of CoJ (SA-venues, 2020)

Figure 3.4: View of Randburg area in Region B (Green Johannesburg, 2009)

Figure 3.5: No urban forest canopy visible in this view of Soweto, Region D (Cedarberg Africa, 2020)

Currently (2020) the city is divided into seven management regions (Figure 3.1) named Regions A to G (Nastar & Ramsar, 2012). For the purpose of this study, it was decided to collect data mainly in Regions C and D and to supplement the data with data from the other regions. This decision was based on logistics and the need to have data from both previously advantaged areas and previously disadvantaged areas. In South Africa the term “previously disadvantaged” refers to black, coloured and Indian people who were socially, economically and educationally underprivileged and deprived by the previous South African government (Mokoena, 2006). Region C is mainly a previously advantaged area, similar to the areas depicted in Figures 3.3 and 3.4, and Region D is a previously disadvantaged area (Figure 3.5). The aim of the study was to identify disparities in these two distinctly different areas. Data was also collected in Regions A, B, E and F.

Region A is the northern region of the city and borders Centurion, a part of the Tshwane Metropolitan Municipality, to the north and Mogale City to the west. To the east it borders Tembisa, part of the Ekurhuleni Metropolitan Municipality and on the south, it borders Alexandra, Sandton, Randburg and Roodepoort. It comprises suburbs such as Midrand, Sunnninghill, Fourways, Dainfern, Diepsloot and Ivory Park (Joburg, 2018).

Region B is in the centre of the city. To the west and north-west, it borders Region C (Roodepoort and the West Rand), to the east, it borders Region E (Bryanston and Sandton), to the south-east, it borders Region F (the inner city) and to the south-west it also shares a border with Region D (Soweto). It comprises suburbs such as Randburg, Rosebank, Emmarentia, Greenside, Melville, Northcliff, Parktown, Hyde Park and Houghton (Joburg, 2018).

Region C is home to Roodepoort and surrounding suburbs such as Braamfisherville, Florida, Honeydew, Cosmo City, Strubensvalley, Tsepisong, Weltevreden Park and Wilgeheuwel. It borders Region A (Diepsloot and Kya Sands) to the north, Region B (Rosebank and Northcliff) to the east and Region D (Soweto) to the south. To the west of the region is Mogale City (Joburg, 2018).

Region D encompasses the whole of Soweto. Suburbs in Soweto include Diepkloof, Meadowlands, Orlando East and West, Pimville and Protea Glen. The established areas of Region D are composed largely of the old "matchbox" houses built to provide cheap accommodation for Johannesburg's workers during the apartheid era. Prosperous areas such as Diepkloof Extension and Protea North are scattered through the region, but large areas of informal settlements (also referred to as shanty towns or squatter settlements (Beavon, 2004)) are still present and located in Doornkop/Thulani, Ebumnandini, Protea South, Chris Hani, Slovo Park and Freedom Square (Joburg, 2018).

Region E comprises many of Johannesburg's older established suburbs (Houghton Estate, Oaklands, Orange Grove, Kew and Norwood) and includes many of the city's newer suburbs such as Sandton, Woodmead and Rivonia. To its north-east border are the suburbs of Modderfontein, Linboro Park and Greenstone Hill and the township Alexandra. The region shares boundaries with Region A (Sunninghill and Midrand) in the north, Region B (Hyde Park and Rosebank) in the west and Region F (Johannesburg CBD) in the south. To the east of the region is the city of Ekurhuleni (Joburg, 2018).

Region F forms the south-western part of the city, with Region E (Houghton and Orange Grove) and Region B (Parktown) to the north, the Ekurhuleni Metropolitan Municipality to the east and Regions D (Soweto) and G (Joburg South) to the west. It includes the suburbs Southgate, Gleneagles, Johannesburg South, Nasrec and Mayfair, as well as the entire Johannesburg inner city (Newtown, Berea and Hillbrow) (Joburg, 2018).

Region G is the southernmost region and borders Soweto in the north-west, and Region F (Southgate and Johannesburg South) suburbs include Lenasia, Zakariyya Park, Eldorado Park, Ennerdale, the Greater Orange Farm and Weilers Farm area (Joburg, 2018).

3.5 Research design and methodology

The research is aligned with the objectives stated in Chapter 1 and individually described highlighting the research instruments, data collection and use.

3.5.1 Objective 1: To conduct an inventory of the project

Evaluation research design was used to analyse the inventory data of the GSTP project, determining the status quo of the project and answering the question of whether the intended outcomes of the project had materialised after an eight-year period. Evaluation research is developed to provide clarity on whether an intervention such as the tree planting project was successfully implemented (Mouton, 2001). The data were analysed using Microsoft Excel and used as a basis for the field inventory data of objectives 2, 3, 4 and 5 as it identified tree species and locations for the measurement and assessment of the tree planting project.

3.5.1.1 Data collection

JCPZ provided a verified tree register of the trees planted during the project. The number of trees on the inventory was verified as planted by JCPZ on 27 July 2011. The tree register was used as the data source and basis for systematic *in situ* field observations to collect the data for the study. The data collected during the systematic *in situ* field observations included the tree species planted, verified planting locations and verified existence or non-existence of the planted trees.

3.5.1.2 Sample structure and size

The data were collected during 2015 to 2017. The tree register was used for the identification and verification of the locations of the trees. An in-depth analysis of the tree register was conducted to estimate the existing trees using the tree register of Regions C (previously advantaged area) and D (previously disadvantaged area) and was supplemented with data from Regions A, B and E (combination of both advantaged and disadvantaged areas) to include data from the other regions of the city as well. The *in situ* verification was conducted using a representative sample (n = 2 908) of the trees of the tree planting project.

3.5.1.3 Methodology to verify and analyse the tree register

The first part of the research was conducted using a desktop study of the verified tree register. The in-depth analysis of the tree register involved checking the information on the register and verifying the number of trees and calculations. The location data on the tree register were checked and used to group the data into planting location categories such as streets and parks, which included shopping centres, wetlands, cemeteries, schools and sporting complexes. The location data were used to identify the number of trees planted in streets, suburbs, regions and in previously advantaged and previously disadvantaged townships or areas.

Subsequent to confirming the number of the trees in the register, Google street view was used to verify the tree planting locations in the register and identify tree species where possible. The Google street view verification process as explained by Li, Zhang, Li, Richard, Meng and Zhang (2015) was implemented. Google street view (Figure 3.6) provides a 360° panorama of the street, which is presented interactively over the Web. An attempt was made to search for and find all the locations where trees were planted, as per the tree register. Each street location was observed in either a southern or western direction, depending on the physical direction of the streets. The trees that were found on the Google street view images were identified and the existing trees counted. Both sides of the street were scrutinised concurrently during the viewing process. The tree species (where applicable) and numbers were entered onto a Microsoft Excel spreadsheet for data analysis.

Figure 3.6: Example of Google street view image, identifying tree species and location of trees (https://www.google.co.za/maps/@-26.2851605,27.8531965,3a,75y,280.76h,91.74t/data=!3m6!1e1!3m4!1sD45QFnHUPhjT--wXEHS-ww!2e0!7i13312!8i6656

The second part of the process (systematic *in situ* field observations) was conducted where Google street view could not provide proof of the trees due to timing of the images on Google street view. Site visits and observations as described in Koeser et al. (2014) were conducted, including tree species identification, confirming the existing number of living trees per location and identifying the missing trees where possible. The data were entered onto a Microsoft Excel spreadsheet for data analysis.

The data collected during the Google street view process and the site visits was analysed and compared with the number of trees originally planted, recorded and verified on the tree register. To estimate the number of existing trees for the entire project, the data from the systematic *in situ* field observations in Regions C and D was combined and extrapolated.

The data from the study provided information on the tree species planted, the number and location of the tree species and the estimated number of existing and missing trees. This information was used to update the JCPZ tree register and collect data for the other objectives of this research study.

The updated JCPZ tree register was used to compile a framework for an inventory for the project by consulting existing international tree inventories and including the baseline data described above. The results from the systematic *in situ* field observations of the trees (tree species identification, measurements and site feature data) were utilised to compile the inventory. This framework may also be used for the entire urban forest of the CoJ when the city decides to embark on a quantification of this resource.

3.5.1.4 Measures to ensure consistency of the process/results

The researcher captured the entire dataset onto Microsoft Excel spreadsheets and the statistician employed for the study validated the data by checking for outlyers and uniformity to ensure consistency of the process and the results.

3.5.2 Objective 2: To determine the interaction between age and growth parameters of the trees and to predict tree growth

To determine the interaction between age, stem diameter, tree height and crown dimensions of the trees, data were collected using existing scientific research protocols by Peper et al. (2001a), Stoffberg et al. (2008, 2009, 2010), McPherson and Peper (2012), Peper et al. (2014), McPherson et al. (2016) and VolCalc software developed by Barrett and Brown (2012). The data were used to determine if the VolCalc software program could be used to calculate growth parameters of urban trees. The data were also used to determine the relationships between the age, stem diameter, height and crown dimensions of the trees, to predict tree growth for the individual tree species as the first part of the study and to develop new allometric equations for these tree species as the second part of the study.

3.5.2.1 Data collection

The updated JCPZ tree register (developed in objective 1) was used for the data collection. The tree register data were used to identify and select the trees from which data were to be collected.

During data collection, trees were identified and measured and photographic evidence (digital photo) of each tree with the visible 1.5 m measuring staff was captured and the GPS of the trees was recorded. Data were collected from the following indigenous tree species: *Celtis africana*, *Combretum erythrophyllum, Olea europaea* subsp. *africana, Searsia lancea* and *Searsia pendulina.*

The trees measured were planted between 2005 and 2010 and their ages derived from the planting dates on the JCPZ tree register. The planting date refers to the year during which the trees were physically planted. The planting specification from JCPZ stipulated that the stem diameter (taken at 50 mm from the base of the trees) had to be a minimum of 30 mm on the day of planting and the tree height had to be 2 m from the base to the tip of the crown. Most of the trees were provided in 50-litre bags at an estimated age of four years (Van der Merwe, 2016).

3.5.2.2 Sample structure and size

To determine the interaction between age and growth parameters of the trees the sample structure was determined by the distribution of the tree species and the availability of a suitable digital image of a sample tree. Only tree species that were found in both streets and parks were used for this part of the study and some of the digital photographs were unsuitable and discarded. Therefore, the sample consisted of *Celtis africana* (n = 358), *Combretum erythrophyllum* (n = 543), *Olea europaea* subsp*. africana* (n = 266) and *Searsia lancea* (n = 286). There were not enough digital photographs of *Searsia pendulina* and this tree was excluded from this part of the study.

The sample for the development of new allometric equations or the second part of the study included the tree species and numbers of the first part of the study, as well as *Searsia pendulina* (n = 28). *Searsia pendulina* could be included as there was enough data available from the Tshwane research study (Stoffberg, 2006) for this species to ensure that the results were valid.

3.5.2.3 Method for data collection

The VolCalc software program uses measurements drawn on a digital photograph to determine tree dimensions. To calibrate, a known sized and visibly marked item or measuring rod must be placed directly adjacent to the tree to be photographed. Therefore, photographic evidence was taken of the tree with a 1.5 m measuring rod placed adjacent to the tree and captured using a digital camera (Figure 3.7). The measuring staff was positioned close to each tree in a vertical position, in such a way that the marks on the measuring staff were visible on the photo. The measuring staff was divided in 0.25 m sections with red tape (Barrett & Brown, 2012). The photo number of the individual tree was recorded on the field form next to the relevant tree name.

Figure 3.7: Example of photo showing measuring staff in vertical position; marks on the staff are visible, next to tree stem

3.5.2.4 Method to determine tree dimensions and interaction between age, stem diameter, tree height and crown dimensions

VolCalc program uses lines that stretch as the mouse cursor is shifted from the anchored point to a desired point on the screen called 'rubber bands' to calibrate and mark off distances between the tree parameters on digital photographs. The rubber band length is determined by calculating the number of pixels the band covers and converting them into metres by multiplying this value by a conversion factor. The tree dimension parameters are marked using rubber bands to identify overall tree height (a), height of maximum canopy diameter (b), height of first leaves (c), maximum canopy diameter (d), base diameter of foliage at height of first leaves (e), crown height (f) and height of tree base (g) as visually explained in Figure 3.8. The crown height (f) is calculated as (a – b) and the height of tree base (g) is calculated as (b – c). Once the dimensions are marked off, VolCalc determines the volume of the tree and the information stored (Barrett & Brown 2012).

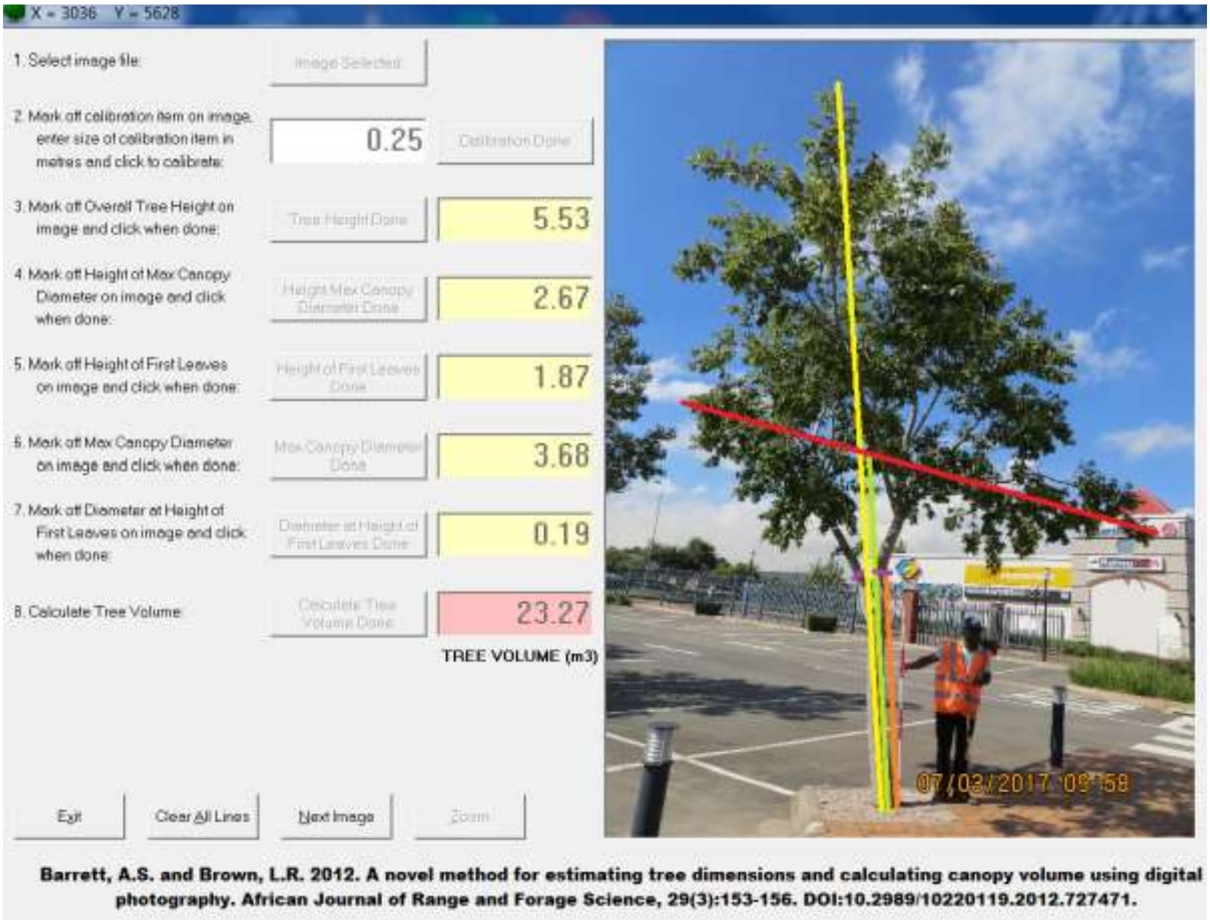


Figure 3.8: Dimensions measured for each tree during data collection process (adapted from Barrett & Brown, 2012).

In Figure 3.8, the lines represent the rubber bands, the yellow line is the tree height, the green line is the height of the maximum canopy, the orange line is the height at first leaf and the purple line is the diameter at first leaf.

Interactions or comparisons of the growth parameters of the trees were determined between regions in the CoJ and per species, between sidewalks, medians in streets and between streets and parks in the different regions. These results indicate preferred locations to plant trees, between sidewalks and medians in streets and between streets and parks.

3.5.2.5 Method to determine allometric equations

The purpose of this process was to develop allometric growth relation estimates and growth equations for the trees in this study. Growth parameters (DBH/CBH, tree height and crown dimensions) are used to model the growth over time and may also be used to model tree biomass and urban forest carbon sequestration. Very few allometric biomass regressions exist for southern African tree species and the logarithmic functions tested by Stoffberg (2006) were applied to the data. The growth relationship between DGL/CGL and DBH/CBH for four tree species were determined using scatter plot diagrams. The relationship of DGL/CDL and

DBH/DBH was determined for each of the VolCalc growth parameters (tree height (m), height of maximum canopy diameter (m), height at first leaf (m), maximum canopy diameter (m), stem diameter at first leaf (m) and volume (m^3)) for the four tree species using scatter plot diagrams. The scatter plots with trendlines and R^2 values were used to determine which of the growth parameters could be used successfully to develop growth equations for the trees in this current study.

In analysing stem diameter growth, several growth curve models were tested (Stoffberg, 2006):

(1) Exponential (Zhang, 1997): $Circ = a * e\left(\frac{-b}{t+c}\right)$

(2) First degree logistic (Brewer, Burns & Cao, 1985): $Circ = a\big(1 + b\exp(ct)\big) - 1$

(3) Gompertz (Du Toit, 1979): $Circ = a\exp(-b(ct))$

(4) Lundqvist (Brewer et al., 1985): $Circ = a(-bt - c)$

(5) Logarithmic model (Peper et al., 2001a, 2001b): $Circ = a(\log(t+1))b$

Where:

Circ	= Stem circumference (mm)
a, b and c	= Parameters to be estimated from the data
t	= Time (tree age in years)

Other alternative research methods were also employed to investigate the possibility of developing growth relationship equations for the trees and to estimate by allometric means alternative, plausible and more correct ages for the trees.

Two methods were applied to investigate the possibility of growth relationship development. Firstly, growth parameter data from this current study (Johannesburg study) was combined with primary data from the study by Stoffberg (2006), hereafter referred to as the Tshwane study. The aim was to investigate if the addition of smaller and large tree data could improve the growth relationships for the Johannesburg study. The combined data were used to draw scatter diagrams to determine new R^2 values and the results were statistically analysed. This was done for *C. erythrophyllum*, *S. lancea, O. europaea* subsp. *africana* and *S. pendulina* tree species only, as *C. africana* and the other tree species in the study were not investigated in the Tshwane study. The parameters for this part of the study were DGL and age; DBH and age; DGL and tree height; DBH and tree height; and crown height and age, as these were the only parameters investigated by both studies.

Secondly, the combined data from the Johannesburg and Tshwane studies were applied to best fitting growth equation models presented in McPherson et al. (2016) and tested by Peper et al. (2014). These models were developed over time and are specific to species and climate zone (regions in the USA). They aim to predict DBH using tree age and tree height, crown diameter and leaf area. Where models for the same tree species were available, they were applied to data from this study, but where no models were available, the model for a similar tree species was used. Tree species in similar climatic conditions with similar growth shapes and sizes were identified and these models were used. As these equations were based on DBH and not CBH, the CBH measurements of the study were converted to DBH prior to doing the calculations.

The following models were tested:

(6) Linear: $y_i = a + bx_i + \frac{\epsilon_i}{\sqrt{w_i}}$

(7) Quadratic: $y_i = a + bx_i + cx_i^2 + \frac{\epsilon_i}{\sqrt{w_i}}$

(8) Log-log: $\mathrm{In}(y_i) = a + b\mathrm{In}(\mathrm{In}(x_i + 1)) + \frac{\epsilon_i}{\sqrt{w_i}}$

Where y_i is the measurement of tree *i*, *a* is the mean intercept, *b* is the mean slope, x_i is the DBH or age of tree *i*, E_i is the random error for tree *i* with $E_j \sim N(0,\sigma^2)$, σ^2 is the variance of the random error, and w_i is a known weight that takes on one of the following forms: $w_i = 1$, $w_i = 1/\sqrt{x_i}$, $w_i = 1/x_i$, $w_i = 1/x^2$.

Microsoft Excel-formatted equations for the above equations were also presented by McPherson et al. (2016) and used in this study:

(9) Linear = a + b x (age or DBH)

(10) Quadratic = a + b x + c x *x*^2

(11) Log-logw1 = EXP(a + b × LN(LN(age or DBH +1) + (MSE/2)))

(12) Log-logw2 = EXP(a + b × LN(LN(age or DBH +1)) + (SQRT(age or DBH) + (MSE/2)))

(13) Log-logw3 = EXP(a + b × LN(LN(age or DBH +1)) + (age or DBH) + (MSE/2))

(14) Log-logw4 = EXP(a + b × LN(LN(age or DBH +1)) + (age2 or DBH 2) + (MSE/2))

McPherson et al. (2016) highlight an important constraint when applying these growth equations to measured tree variables. Equations predicting DBH from age may produce negative values for young trees, which may cause persistent difficulties for using DBH to predict tree height and other variables.

The process to use the allometric equations to predict tree component dimensions (DBH, tree height, crown diameter, crown height and leaf area) as described by McPherson et al. (2016) is as follows:

Step 1: Identify the correct equation to use for each of the tree species or their alternatives. It is important to choose an equation relative to the tree species in a specific region as climate differences in regions affect tree growth.

Step 2: Calculate tree height from DBH by looking up the equation name and coefficients (constant values) in the tables provided.

Step 3: Calculate crown diameter from DBH by looking up the equation name and coefficients in the tables provided.

Step 4: Calculate crown height from DBH by looking up the equation name and coefficients in the tables provided.

Step 5: Calculate leaf area from DBH by looking up the equation name and coefficients in the tables provided.

The predicted growth parameters were then correlated with the data from the study and differences identified.

Due to the discrepancies in the ages of the trees, a final attempt was made to determine the correct ages of the trees in the Johannesburg study by applying the "Tree age and correlated sequestrated carbon, stem circumference and stem diameter table" provided by the Tshwane study (Stoffberg, 2006) for indigenous tree species, to the CGL measurements of the study. This table provided the tree age in quarter years and correlated stem diameter in mm for *C. erythrophyllum, S. lancea* and *S. pendulina*. The study also presented combined species regressions for other tree species that had similar growth rates. For example, the combined *C. erythrophyllum* and *S. lancea* estimates were used for *C. africana* and *O. europaea* subsp. *africana*. New ages (relative to the measured CGL in mm) were determined by the information presented in these tables. Then the new ages were correlated with the growth parameters tree height and maximum canopy diameter to identify whether relationships existed. Scatter plot diagrams were drawn using age as the dependent variable and R-squares identified to determine significance.

3.5.2.6 Statistical analysis

The VolCalc growth parameters (tree height (m), height of maximum canopy diameter (m), height at first leaf (m), maximum canopy diameter (m), stem diameter at first leaf (m) and volume (m^3)) data were analysed using one-way analysis of variance (ANOVA). An ANOVA is used to determine whether there are any statistically significant differences between the means of two or more independent or unrelated groups of data (Kim, 2017). All growth parameter means were compared and where differences were significant, the Duncan multiple range test (DMRT) was used for separation between treatment means at a 95% significance level. The ANOVA test indicates that the means are significantly different but does not indicate which of the means are different. DMRT is used to measure specific differences between the pairs of means. It is classified as a post hoc test and is used to make multiple or pairwise comparisons that utilise a studentised range statistic to compare the sets of means (Lasisi & Abdulazeez, 2017). The data were statistically processed using Microsoft Excel and statistical analysis software Statistica version 10 package for Windows.

3.5.3 Objective 3: To complete a carbon assessment and determine the value of the tree planting project

To complete a carbon stock assessment and determine the value of the trees, data were collected, and research conducted using existing scientific research protocols developed by Stoffberg et al. (2010). Standing carbon stock and potential carbon sequestration as well as the monetary value of the standing trees and the projected value over a 30-year period were calculated.

3.5.3.1 Data collection

The updated JCPZ tree register (developed in objective 1) was used for the data collection and to identify and select the trees from which data were to be collected.

The data collected for this part of the study was tree circumference measurements taken at 50 mm above ground level (CGL) or just above the basal swelling and at breast height at 1.37 m above ground level (CBH). Measurements were taken using a tape measure, marked in linear units of millimetre lengths. The circumferences were used to calculate and determine the net standing carbon stock. The standing carbon stock refers to the net quantity of carbon stored by the trees at the time of measurement.

CGL and CBH for multi-stemmed trees were calculated as the square root of the sum of the squared stem diameters. For a single-stemmed tree, the calculated CBH or CGL is equal to the single diameter measured. The following formula (McPherson et al., 2016) was used to calculate the CGL and CHB of multi-stemmed trees:

(a) $DGL \text{ or } DBH = SQRT[SUM(stem\ diameter^2)]$

For example, a multi-stemmed tree with stems of 12.22, 13.22, 3.82, and 22.12 would be calculated as:

DGL or DBH = SQRT ($12.22^2 + 13.22^2 + 3.82^2 + 22.12^2$)

= SQRT (51.38)

= 28.74

The DGL was replaced with CGL and DBH with CBH in the formula to determine the circumference of a multi-stemmed tree.

Data were collected from these indigenous tree species: *Afrocarpus falcatus* (Thunb.) C.N. Page (Outeniqua yellowwood), *Celtis africana* Burm.f. (white stinkwood), *Combretum erythrophyllum* (Burch.) Sond. (river bush willow), *Harpephyllum caffrum* Bernh. (wild plum), *Kiggelaria africana* L. (wild peach), *Olea europaea* L. subsp. *africana* (Miller) P.S. Green (wild olive), *Schotia brachypetala* Sond. (weeping boer-bean), *Searsia lancea* (L.f.) F.A. Barkley (karee), *Searsia pendulina* (Jacq.) Moffett (white karee), *Senegalia galpinii* (Burtt Davy) Seigler & Ebinger (monkey thorn), *Vachellia karroo* (Hayne) Banfi & Galasso (sweet thorn), *Vachellia sieberiana* var. *woodii* (Burtt Davy) Kyal. & Boatwr. (paperbark acacia). The names given in this thesis were verified using the Global Biodiversity Information facility (GBIF Secretariat, 2019).

One exotic tree species - *Liquidamber styraciflua L.* (sweetgum) – was identified as part of the project and excluded from carbon calculations as it was exotic. Other exotic *Celtis* species (*Celtis orientalis* L. (pigeon wood) and *Celtis sinensis* Pers. (Chinese elm)) were identified as part of the project, but due to uncertainty of correct identification caused by the cross-pollination ability of the species, creating hybrid species, and the difficulty in identifying hybrids as juvenile morphology usually persists until the plant is 1-2 m in height (Whittmore & Townsend, 2007), all the *Celtis* species were reported on as *Celtis africana*. JCPZ also indicated that only *Celtis africana* tree species were planted. Therefore, this study reports on all the *Celtis* species as *Celtis africana.*

3.5.3.2 Sample structure and size

To determine the sample structure and size of the data to be collected, a pilot study was conducted between February and May 2016. The pilot study provided the data required to determine the sample size of the larger study and clarified the conceptual information to be collected for the project. It was decided to use both a street and a park as a pilot study as the trees planted during the project were planted mainly in streets and parks. Street trees planted in Chris Hani Street and those planted in Orlando West Park, both in Soweto (Region D), were used as the pilot sample sites.

To provide data for research use in urban forests, tree sampling is a good option when 100%, full or complete inventories are not feasible, although a comprehensive inventory will provide the most useful data (Dwyer et al., 2000; Nowak, Walton, Baldwin & Bond, 2015). According to Nowak et al. (2015), the sample size is determined by available funding, the types of variables required (tree species, CBH, CGL, maintenance requirements etc.), precision required (an acceptable standard error for the type of information required), available data (tree inventories available, plant names and addresses supplied) and the sample design (random sampling or comprehensive inventories required).

A sample inventory was conducted for this research study due to time, human resources and budget constraints involved in collecting data from 200 000 trees. The sample size (number of trees measured) of the target population (200 000 trees) will determine the accuracy of the results and will provide increased reliability and statistically eligible data to reflect the population. Large sample sizes increase the accuracy in the results but also increase the project costs. It is important to have reliable results for any research and therefore it is critical to determine the sample size that will ensure valid results.

The standard error percentage was determined to ensure validity of the results. The lower the standard error, the greater the confidence in the estimation of the carbon and the precision of the estimate (Nowak et al., 1996; Nowak et al., 2015). The aim was a 95% confidence level and a percentage error of less than 3% (Nowak et al., 1996; Nowak et al., 2015) in determining the number of trees per species and per suburb to be measured. The pilot study showed that a sample size of 20 trees per species, per street or park, per suburb was sufficient to provide results at a confidence level of 95%.

The following statistical method procedure and calculations were used to determine the standard error (SE) percentage of the sample size:

- Step 1: Calculate the mean (m) of the sample.
    - Total of all samples (measurements) divided by the number of samples (number of trees measured or sample size - *n*).
- Step 2: Calculate each measurement's deviation from the mean.
    - Mean minus the individual measurement (i).
- Step 3: Square each deviation from mean.
    - Squared negatives become positive.
- Step 4: Add the squared deviations.
    - Add up the squared numbers from step 3.
- Step 5: Divide that sum from step 4 by one less than the sample size.

- (n-1) that is, the number of measurements minus 1.

- Step 6: Take the square root of the number in step 5.
  - This is the standard deviation (SD).
- Step 7: Divide the standard deviation by the square root of the sample size (n).
  - This is the SE.
  - Divide the SE by 100; this is the % SE.

Calculations from the steps above:

If there are 3 measurements, n = 3.

- Step 1: m = (n1 + n2 + n3/3)
- Step 2: (m - i)
- Step 3: $(m - i)^2$
- Step 4: $\sum(m - i)^2$
- Step 5: $\sum(m - i)^2/(n - 1)$
- Step 6: SD = Square root of $\sum(m - i)^2/(n - 1)$ or $\sqrt{}\sum(m - i)^2/(n - 1)$
- Step 7: SE = SD/$\sqrt{n}$

  SE% = SD/$\sqrt{n}$/100%

Data for the carbon calculations was collected from 2 498 trees consisting of *Afrocarpus falcatus* (n = 40), *Celtis africana* (n = 834), *Combretum erythrophyllum* (n = 732), *Harpephyllum caffrum* (n = 10), *Kiggelaria africana* (n = 9)*, Olea europaea* subsp. *africana* (n = 347), *Podocarpus* species (n = 18), *Schotia brachypetala* (n = 20), *Searsia lancea* (n = 379), *Searsia pendulina* (n = 45)*, Senegalia galpinii* (n = 41), *Vachellia karroo* (n = 3) *and Vachellia sieberiana* var. *woodii* (n = 20).

Therefore, the sample size for this study was 2 498 trees. This is a sample size of 0.012% of the 200 000 trees planted. Even though the sample size percentage is low, the SE% confirmed the sample size (20 trees per species per suburb) to be representative of the trees planted and sufficient for the purpose of the study. The trees were planted over a six-year period and data from each of the years was collected across the city.

3.5.3.3 Method for data collection

Ensuring that the correct, quality data were collected to answer the research questions depends on the development and implementation of a strict research methodology (Hofstee, 2006). The collection of data for this part of the study involved measuring tree stems. Most of the data were collected in Regions C and D and supplemented with data from Regions A, B, E and F. No data were collected in Region G. Data from the pilot study was included as part of the study.

The stem circumference of the trees was determined with a tape measure at 50 mm above ground level (CGL) or just above the basal swelling or root collar (providing a calculated diameter at ground level). Before measuring the CGL, the loose soil or grass material surrounding the tree was removed to expose the root collar and the measurement was taken above the swelling of the tree trunk. Circumference at breast height (CBH), which is measured at 1.37 m above ground level, was measured by circumference and calculated to present diameter. Where stem branching occurred below 50 mm, the tree is referred to as a multi-stemmed tree and a maximum of three CGL measurements were taken. Where branching occurred at or below 1.37 m, a maximum of five CBH measurements were taken. Where the main stem was divided into a number of small lateral branches measuring less than 10 mm each, below 1.37 m, the CBH was not taken. An attempt was made to always take the measurements perpendicular to the vertical axis of the stem. If there were skew trees or trees leaning to the side, the measurement was taken at the point where the tree stem was at the vertical height of 1.37 m from the ground.

The aim of the data collection was to collect data for 20 individual trees per species, per suburb, which represented trees planted at the same age during the same planting period/year. To prevent selecting the best individual trees during data collection, which results in biased data (Mouton, 2004), a stratified sampling methodology was followed where trees were randomly selected from the beginning of each street block by use of a random number table. Data were collected consecutively, from each of the 20 trees starting from the number selected on the random number table. The data collection was conducted from March 2017 and was concluded in July 2017.

Data were collected from street tree and park locations stipulated in the JCPZ tree inventory. No data were collected from schools, private properties and inaccessible locations. Data could not be collected from invalid, incorrect, incomplete addresses or where no address was provided on the inventory. No data were collected if there were fewer than 10 of the trees planted, per address, still present.

During this data collection process, some of the trees in the streets could not be measured and used as part of the carbon calculations. These trees did not form part of the 20 trees per location; they were included as additional to the 20 trees measured on the dataset and were labelled as “trees not measured”. The following categories of trees were not measured but data were collected to categorise them. Photographic examples of these trees are included in Chapter 4.

- Missing tree: Where there was proof of a tree basin where a tree had been planted previously but did not exist during the fieldwork, it could not be measured.
- Dead tree: Trees that were clearly dead were not measured.
- Broken tree: Extremely damaged or broken trees that were still alive but either their stem/branches or crown were damaged irreparably. These trees were not measured.
- Coppice growth: Trees that had reverted to only coppice growth and presented without a main stem or stumps with mainly coppice growth were not measured.
- Dead stumps: The presence of only a dead stump remaining in the planting position indicated that a tree previously existed. These stumps were not measured.

Variables were included during the data collection to ensure consistency and reliability of the information and to provide for future follow up. The variable name, a description of the variable and a reason for the choice and use of each variable are provided in Table 3.1.

Table 3.1: Variable names, descriptions and reasons for choice of each variable on field form

Variable name	Description of the variable	Use of the variable	Reason for including the variable
Species code	Four-letter code consisting of the first two letters of the genus name and the first two letters of the species name	To identify the tree species To have a stable abbreviation for each species name	Including a species code improves efficiency when collecting field data
Date	Date when measurement took place	To track data and know when the information was gathered	The data provides a reference for future measurements and determination of effects in a certain time frame
Names	Names of fieldworkers	To know who measured the trees	To track data should there be inconsistencies in measurements
Park/street	Indication if tree was planted in either a park or a street	To identify where data were collected	To determine variability in planting locations and determine where plants grow better
Median/sidewalk	Indication if the tree was planted on the median or on the sidewalk	To identify where data were collected	To determine variability in planting locations and determine where plants grow better
Suburb	Suburb name where the trees were measured	To locate the tree in future	To determine the sample size for this and future studies To identify the location of the tree

Street	Street name where the trees were measured, the name of cross street perpendicular to the street where the first tree was measured or where the park was located and the name of the cross street perpendicular to the street where the last tree was measured or where the park was located	To locate the tree in future	To locate the tree in future using the street name as well as the specific location in the street – between the two streets perpendicular to the street location
Latitude	Latitude noted in degrees, minutes and seconds	To locate the tree for future measurements	To locate the tree for future measurements
Longitude	Longitude noted in degrees, minutes and seconds	To locate the tree for future measurements	To locate the tree for future measurements
DGL/CGL	Diameter at ground level or stem circumference at 50 mm above ground or just above the basal swelling; maximum of five stems	To use in equations to determine carbon stocks and for allometric equations	Internationally known measurement used to determine carbon stocks and for allometric equations
DBH/CBH	Diameter at breast height or stem circumference at 137 mm from ground level; maximum of five stems	To use in equations to determine carbon stocks and for allometric equations	Internationally known measurement used to determine carbon stocks and for allometric equations
Year	The year indicated in the tree register as the year when the tree was planted	To determine the tree age	For statistical purposes
Photo	Digital photograph identification number	To use in calculating growth parameters using VolCalc software program	To have dated, digital evidence of the specific tree

Notes	Observations of tree quality and aspects pertaining to specific tree	Observations such as tree quality, pest invasions, land use and land cover aspects that could influence data analysis	To use for clarification of results

3.5.3.4 Estimation of carbon sequestration

The carbon stock was calculated for indigenous trees only.

The growth rate equations for urban, indigenous South African trees by Stoffberg et al. (2008) were used for this study and is based on the generic biomass calculation equation for South African savannah trees as presented by Shackleton (1997). The calculations (Eq.1) to (Eq.14) were completed for each individual tree, and the data were combined and used for extrapolations, to determine the future value of these trees.

Stem circumference (CGL) was measured for each tree. The ages of the trees were determined from the JCPZ tree register and four years were added as the trees were approximately four years old at planting date (Van der Merwe, 2016).

The carbon stock calculations consist of a few steps. The first step was to predict the stem circumference at ground level (Eq.1) using pre-estimated constants and the methodology presented by Stoffberg et al. (2010) which is based on Peper et al. (2001a). The constants have different values for different species and are presented in Table 3.2. The calculation is as follows:

(Eq.1) $C_{\mathrm{i}} = \mathrm{EXP}(\mathrm{MSE}/2 + (\,\hat{\mathrm{A}} + b(\ln(\ln(x + 1)))))$

Where:

c_i = Estimated value of the stem circumference of the i[th] tree in millimetres

EXP = Inverse of the natural logarithm; by the natural logarithm is meant $\log_e$, also referred to as *ln*

Â, b, MSE = Pre-estimated constants which have different values for different species, Mean Sum of Squares (MSE)

ln = Inverse log transformed (formula)

x = Value of the age of the tree in years

Table 3.2: Regression coefficients and mean standard error values for predicting the estimated stem diameter growth as well as coefficients of determination (Stoffberg, 2006)

Tree species	***Â***	***b***	**MSE**
Combretum erythrophyllum	4.58352	2.44085	0.14804
Searsia lancea	4.95616	1.74761	0.057522
Searsia pendulina	4.53125	2.21533	0.051892
Combined *C. erythrophyllum* and *S. lancea*	4.76982	2.05338	0.11204
Combined *S. lancea* and *S. pendulina*	4.87405	1.78046	0.059088

The regression coefficient estimations developed for individual species such as *C. erythrophyllum, S. lancea* and *S. pendulina* were used and where individual regression coefficient estimations do not exist, combined estimations were used (Stoffberg, 2006). The combined *C. erythrophyllum* and *S. lancea* estimates were used for *V. karroo, V. sieberiana* var. *woodii*, S. *galpinii* and *C. africana, O. europaea* subsp. a*fricana*, *S. brachypetala*, *A. falcatus* and *Podocarpus* species (in Gauteng) as their approximate size lies between that of *C. erythrophyllum* and *S. lancea.* Combined *S. lancea* and *S. pendulina* were used for *K. africana* and *H. caffrum* as they are smaller trees and their approximate size lies between that of *C. pendulina* and *S. lancea.* The regressions for *S. pendulina* were only extrapolated to 15.5 years and therefore the combined *S. lancea* and *S. pendulina* were used (Stoffberg, 2006).

The second step is to calculate the biomass for an individual tree. This involves determining the total dry matter (TDM) (Eq.2) above ground. Subsequently the root dry matter (RDM) is determined. The RDM is estimated to be 78% of the TDM (Stoffberg, 2006) and therefore the TDM is multiplied by a density factor 0.78. (Eq.3). It is assumed that a certain percentage of the TDM consists of leaf or foliage dry biomass and should be disregarded in the equation. According to Scholes and Walker (1993), an average African savannah tree carbon content of the above-ground biomass is assumed to be 45%, and 5.4% of the TDM is foliage dry biomass. To determine the above-ground carbon (AGC) (Eq.4) the TDM less the TDM multiplied by 0.054 (lowest percentage estimation of the AGC) and then multiplied by the highest percentage AGC estimate (0.45). To determine below-ground root carbon (RC) Scholes and Walker (1993) put an average African savannah tree carbon content of the root carbon as 42% of the root biomass. Therefore, to determine the RC (Eq.5) the RDM is multiplied by 0.42. The total carbon (TC) in kilograms is determined by adding the AGC and the RC (Eq.6). TC divided by TDM (Eq.7) translates to a ratio of 0.7533 of sequestered carbon to above-ground dry biomass. The sum of the standing carbon was determined by adding the results of all the individual trees of each species (Eq.8). Standing carbon stocks (SCS) present the carbon storage in trees as at the time of fieldwork (2017). The carbon sequestration in kilograms was converted to CO_2 by multiplying it by 3.67 (Eq.9). The value of 3.67 reflects the ratio of molecular weight of carbon and carbon dioxide (McPherson & Simpson, 1999; Pearson, Brown & Birdsey, 2007). Equation 10 converts CO_2 to tons (tCO_2) by multiplying it by 1 000. The estimated potential projected total CO_2e sequestration over a period of 30 years for all the trees of the project was calculated by using an extrapolation calculation from Stoffberg (2006). The total number of trees in the study was multiplied by a predetermined carbon value to estimate the carbon value over a 30-year period (Eq.11). The value of the carbon sequestered in the tree species was presented as mean, lower and upper confidence level sequestered carbon (kg) and the value of the carbon at 30 years was selected from a table in Stoffberg (2006), who used tree-based, time and growth rate relationships to enable the creation of carbon sequestration regression equations. This allowed for the calculation of estimated projected (future growth) carbon sequestration by the indigenous trees and estimation of the future carbon sequestration value of the tree planting project over a period of 30 years. The carbon values were converted to carbon dioxide values (Eq.12) and to tons (Eq.13). The conversion to carbon dioxide is necessary to determine the greenhouse gas (CO_2e) removal impacts of the trees through plant growth. Finally, the monetary value of the projected carbon dioxide stocks that will be sequestered over a 30-year period was determined (Eq.14) for South African rand (ZAR) and US dollar (US$). The value was determined by applying the carbon tax of ZAR120.00 per metric ton of CO_2, proposed by the Department of National Treasury (2014) and a hypothetical estimation of US$10 per ton CO_2e.

Calculations:

(Eq.2) $\log b = 2.397(\log c) - 2.441$ with $R^2 = 0{:}94;\ p < {:}00001;\ n = 94$

Where:

b = Biomass (kg) or total dry mass

c = Stem circumference (cm)

This is the answer to equation 1.

(Eq.3) $RDM = 0.78\ x\ TDM$

Where:

RDM = Root dry mass

TDM = Total dry matter

(Eq.4) $AGC = 0.45(TDM - (0.054\ x\ TDM))$

Where:

AGC = Above-ground carbon

TDM = Total dry mass

(Eq.5) $\mathrm{RC} = 0.42(\mathrm{RDM})$

Where:

RC = Below-ground root carbon

RDM = Root dry matter

(Eq.6) $TDM = AGC + RC$

Where:

TDM = Total dry matter

AGC = Above-ground carbon

RC = Below-ground root carbon

(Eq.7) $TC\ /TDM$

Where:

TC = Total carbon

TDM = Total dry matter

(Eq.8) $$a(1) + a(2) + a(3) + \cdots + a(x) = SCS$$

Where:

a(x) = Total carbon for each individual tree

SCS = Total standing carbon stock for the species

(Eq.9) $$SCS\ x\ 3.67 = kg\ CO_2$$

Where:

SCS = Total standing carbon stock for the species

3.67 = Ratio of molecular weight of carbon in kilograms

(Eq.10) $$CO_2\ x\ 1000 = tCO_2$$

Where:

1 000 = Conversion factor from kilograms to tonnes

(Eq.11) $$a\ x\ b = c$$

Where:

a = Number of trees per tree species in the study

b = Predetermined carbon value in kg

c = Projected carbon in kg (mean, lower and upper confidence levels) for all the trees per species

(Eq.12) $$c\ x\ 3.67 = Projected\ CO_2\ for\ all\ the\ trees\ per\ species$$

Where:

c = Projected carbon in kg

3.67 = Ratio of molecular weight of carbon in kilograms

(Eq.13) $$d \ x \ 1000 = e$$

Where:

d = Projected CO_2 for all the trees per species

e = Projected CO_2 in tonnes for all the trees per species

(Eq.14) $$e \ x \ 120.00 = f \ and \ e \ x \ 10.00$$

Where:

e = Projected CO_2 in tons for all the trees per species

120.00 = Carbon tax in South African rand (ZAR) (Department of National Treasury, 2013)

10.00 = Hypothetical estimation of 10 US dollars (US$) per ton CO_2e

f = Monetary value of the projected carbon dioxide stocks that will be sequestered

The different totals were added and results for the entire project delivered.

3.5.3.5 Measures to ensure consistency of the process/results

Measures were implemented to ensure consistency of the process. A stratified sampling methodology was followed using a random number table during the entire data collection process, which eliminated biased sampling selection. On-site training was provided to all the data collectors. The training involved correct use of the research instruments and completion of the field form. Only six different data collectors were used for the data collection process, limiting the chances of variation during the process. Furthermore, the same three data collectors collected 90% of the data. The same field form was consistently used for the entire data collection process and included all the information required for objective 3, which avoided the data collection team having to go back to the research site, preventing inconsistencies.

The researcher captured the entire dataset onto Microsoft Excel spreadsheets and statistical analysis was based on this master spreadsheet dataset. Microsoft Excel was used for data analysis.

3.5.4 Objective 4: To determine the influence of land use, land cover and external factors on the growth of trees

To determine the influence of land use, land cover and external factors (tree maintenance required, the effect of human influence, conflict or damage caused by infrastructure and the presence of pests and diseases) on the growth of the 200 000 trees planted during the Greening Soweto project, a field survey methods was used (Mouton, 2004).

3.5.4.1 Data collection

The data were collected by observations at the same time as the tree measurement and assessment processes were conducted. Land use, land cover and the external factor data were included as variables on the field form. The variable categories were determined from the literature review and informed by the pilot study. All the categories were identified as directly adjacent to, for at least 1m surrounding the tree or directly underneath the specific tree canopy. Where more than one land use, land cover and external factor category was found in the area surrounding the tree stem, all the identified categories were listed.

Land use categories identified and included as variables are described as follows:

- Formal residential land use areas: Formal housing in official city suburb with sealed, tar roads next to the houses and properties with or without perimeter fences or walls. Formal residential areas are serviced by local city councils.
- Informal residential land use areas: Informal housing, also referred to as shanty towns or squatter settlements (Beavon, 2004), are temporary structures in unofficial developments of the city. These areas have gravel or non-sealed roads and are not serviced by the city council.
- Commercial land use areas: Formal business including individual shops, shopping centres, fuel stations, office buildings and other structures used by residents for purposes of business and/or leisure. Buildings or structures are usually larger than those in formal residential areas and there is more traffic in the land use.
- Industrial land use areas: Small and/or large factories with the function of producing mainly goods and providing services.

- Education land use areas: Nursery schools, primary and secondary schools and tertiary institutions. This land use area is known for a high volume of traffic during peak hours.
- Religious land use areas: Churches and other religious buildings.
- Government land use areas: Police stations, hospitals and clinics, city council offices and depots.
- Road median land use areas: Open space in the middle and between two opposite directional traffic roads, approximately 150 mm higher than the surrounding roads. Usually denoted by concrete kerb pavement.
- Park land use areas: Green open space, developed, managed and maintained by the city council and used by residents for informal sport and recreation. City council provides facilities such as children playparks, ablution facilities and sports fields. Parks are also used for music festivals and informal gatherings.
- Green open space land use areas: Green open spaces not designated as a park, such as large lawned open areas, and not formally used by residents for recreation. No facilities are provided by the city council, but the area is maintained by the city council.
- Vacant land, land use areas: Land not used for any specific purpose and usually either bare soil or covered in veld grass. Vacant land is not maintained by the city councils.

Land cover categories were identified and described as variables in the research describing the cover of the land for approximately 1m surrounding the tree stem where it is planted in the ground:

- Maintained grass: *Pennisetum clandestinum* (kikuyu) lawn maintained at least by mowing by either the city council or the local residents at a height of between 10 mm and 30 mm. Maintained grass may also include irrigated and fertilized lawn.
- Unmaintained grass: Kikuyu lawn as well as different types of veld grass such as *Panicum maximum* or *Themeda triandra* not maintained by either the city council or residents and allowed to grow to its natural length.
- Bare soil: Bare soil, not covered with any other material (organic or inorganic). The surface of this category usually varies in compaction.
- Paving: Paving such as brick, clay or interlocking brick paving up to the stem or 0.5m away from the tree stem in all directions. Where the tree was planted in paving, but the paving was further away from the stem than 500 mm in all directions, the land cover

class would not be paving, but the land cover class directly next to the stem of the plant.

- Hard landscaping: Hard landscaping constitutes pebbles, rocks and gravel covering the space directly next to the stem of the plant. Hard landscaping always forms part of an executed landscape design.
- Plant beds: A plant bed covered with vegetation such as groundcover or perennials planted directly next to the tree and surrounding the tree. Plant beds form part of an executed landscape design and are maintained by either the local city council or owner of the property directly adjacent to the plant bed.
- Irrigated around the trees: The presence of an irrigation system, either drip, rotary or impact irrigation, visible 500 mm surrounding the tree, with the aim of irrigating the tree.

The following external factor categories and subcategories were identified and are described as part of the variables:

- Tree maintenance required: The type of tree maintenance required to correct and improve the growth of the tree was identified, according to specific subcategories. Where no maintenance was required, it was indicated and recorded as such.
    - "Bark damage" refers to the removal of bark for medicinal purposes or damage to the bark caused by mechanical equipment, requiring treatments such as cleaning of the wounds and applying tree sealant.
    - "Dead branches" refers to the presence of dead branches still on the tree requiring removal by pruning.
    - "Coppice" refers to coppice growth found at the base of the tree requiring removal by pruning.
    - "Pruning" refers to any broken or damaged branches or branches obstructing views or growing in inappropriate directions, requiring removal by pruning.
    - "Skew trees" refers to trees growing at an angle of less or more than 90° perpendicular to the surface, requiring straightening by inserting a tree stake next to the stem and tying the tree to the tree stake with appropriate tree ties.
    - "Wires and cable ties" refers to any obstructive materials surrounding the stem of the tree requiring removal.

- Presence of pests and diseases: Only the presence or absence of a pest or disease was recorded. No attempt was made to identify any insect, pest or disease; neither was the severity of the infestation indicated.
    - No pests or diseases visible to the naked eye, present on the tree stem, branches or leaves were recorded as such.
    - Insect pests such as aphids, scale or borers present on the tree stem, branches or leaves were recorded. Ants were not considered as a pest, but where ants were found on the tree, other/primary pests were located, and the alternative insect recorded.
    - Diseases such as a fungus, bacteria or virus visible to the naked eye, present on the tree stem, branches or leaves were recorded.
- The effect of human influence: The following data were only collected and recorded if the human influence aspects were present during the data collection process and not with regard to the possible effect on the trees in future:
    - Pedestrian traffic using the space directly next to the tree (approximately 1 m surrounding the tree) was recorded. Pedestrian traffic increases the compaction surrounding the tree and was therefore taken into consideration.
    - The presence of informal traders of any produce or services using the space directly next to the tree (approximately 1 m surrounding the tree).
    - Animals such as cows and goats feeding in the space directly next to the tree (approximately 1 m surrounding the tree).
    - Vehicles present in the space directly next to the tree or approximately 1 m surrounding the tree.
    - Bark harvesting or any deliberate removal of bark from the tree stem for medicinal purposes and this plant trade is of great concern in South Africa (Mander, Nthuli, Diederichs, & Mavundla, 2007).
    - Rubble (plastic, tins, paper, glass, wood ash, or similar rubble) surrounding the tree stem (approximately 1 m surrounding the tree) or placed in a heap around the tree stem.
    - Trees located in a maintained surrounding where the lawn surrounding the tree was mowed regularly or the flowerbed was maintained. No presence of neglect in the area directly surrounding the tree visible.

   - Trees located in an unmaintained surrounding where the grass surrounding the tree was not mowed regularly or the flowerbed was not maintained. There were weeds or rubble present in the area directly surrounding the tree.
   - Any other human influence such as oil spills or unknown soil compaction or interference were indicated as “Other”.
- Conflict or damage caused by infrastructure: Infrastructure refers to any humanly created structures or surfaces. Where there was no conflict with any of the infrastructure or subcategories in the area directly surrounding the tree, “no conflict” was indicated. Present conflict was recorded and not potential conflict.
   - Road: Roots of the tree causing damage such as lifting and interfering with the road surface.
   - Kerb: Roots or the stem of the tree causing damage such as lifting and interfering with the kerb next to the road.
   - Paving: Roots or the stem of the tree causing damage such as lifting and interfering with the paving surrounding the tree.
   - Overhead structure: Canopy of the tree causing interference with overhead structures such as power lines.
   - Sidewalk: A sidewalk is defined as a strip of land adjacent to the tree, not covered in paving but covered with lawn. Roots or the stem of the tree interfere with the surface of the sidewalk.

3.5.4.2 Sample structure, process for data collection and measures to ensure consistency of process/results

The same sample structure was followed as described for objective 2, as the data collection of the land use and land cover categories was conducted during the same research process as the measurement of the trees to determine growth relationships of these trees. The updated JCPZ tree register and the same field form for the data collection were used. Data were collected by noting observations and recording variables of each of the trees and the same measures to ensure consistency applied.

3.5.4.3 Statistical analysis

Descriptive and inferential statistics were the two approaches used for data analysis. With regard to the descriptive statistics, frequency distributions were used to describe the influence of land use, land cover and external factors (tree maintenance required, the effect of human influence, conflict or damage caused by infrastructure and the presence of pests and diseases) on the VolCalc growth parameters of trees growing in the CoJ.

The inferential statistical test used was Spearman's rank correlation coefficient (rho) test. This is a non-parametric rank coefficient test that can be used to find the relationship between two ordered categorical variables (McDonald, 2014). In this research, it was used to examine the relationship between the growth parameters and the independent variables such as influence of land use, land cover and external factors. Spearman's rank correlation coefficient measures the extent of the linear relationship between the ranks of the variables. The outcome of the correlation analysis is a +/- rho value, with rho (r) value indicating the magnitude of the relationship and the sign +/- indicating the direction of the relationship (McDonald, 2014). The Kruskal-Wallis test (also a rank-based non-parametric test) was also used to test for significant differences between the volCalc parameters and the variables of land use, land cover and external factors.

A rho (r) value of 0.1 to 0.3 is considered a weak relationship, 0.3 to 0.5 is a moderate relationship and over 0.5 is a strong relationship, indicating a statistically significant relationshop (Grove, Grey & Burns, 2015). The data were analysed using SPSS version 25.

3.5.5 Objective 5: To develop guidelines for new tree planting projects to advise new tree planting in the city, improve survival rates and optimise the value added to the urban forest

The carbon sequestration value of the trees planted during the tree planting project potentially may have presented a significant difference between the value of the existing trees and the value of the project, if all 200 000 trees had still been present and growing. A low survival rate would emphasises the need for guidance and recommendations, to steer future tree planting projects in a sustainable manner, preventing high mortality rates, improving tree growth and health and optimising the value new tree planting projects add to the urban forest.

To construct the basis of the guideline, a comprehensive and well-integrated literature review was conducted, providing a good understanding of the issues and debates as well as the theoretical thinking on the topic, selected from previous studies (Mouton, 2004). For the first part of the study, environmental management literature methodology was systematically reviewed. Secondly, literature was sourced and reviewed using backward chaining and forward chaining and finally, the titles and abstracts of all volumes of the five most prominent journals publishing urban forestry related studies were scanned and reviewed. Data from this structured literature review (described in the literature review section of this chapter) was used to identify aspects that would form the core of the guideline. Additional data were identified from the original literature review of this study to supplement the data from the focused literature review.

3.5.5.1 Structured literature review methodology

For this literature review the systematic review of environmental management literature methodology was applied (Pullin & Stewart, 2006, as described by Nielsen et al. (2013) and Nielsen et al. (2014)). The databases Scopus and Web of Science were used to gather the data and the search was restricted to a single search string with few search terms. The search terms urban * "tree planting" * were used and considered among the categories 'Title, abstract, keywords' in Scopus and the category 'Topic' in Web of Science. Two rounds of selection were undertaken, and relevant articles were identified using the following terms referred to as inclusion criteria: tree planting; tree planting strategy; tree survival; tree mortality; tree establishment and urban forest.

Firstly, literature was eliminated based on the title only and secondly, literature was examined based on the title and the abstract. During this identification phase 517 articles were identified by Scopus and 292 articles by Web of Science. These articles were screened for applicability. Using the articles identified by the screening process, more potential articles were identified by means of backward chaining (searching the literature cited in the articles identified by the search engines used, n = 20) and forward chaining (finding articles which cite the identified articles, n = 4) as described by Hilbert et al. (2019). Finally, the titles and abstracts of all volumes of the five most prominent journals publishing urban forestry related studies (*Journal of Arboriculture* (1976 to 2005), *Arboriculture & Urban Forestry* (2006 to present - the International Society of Arboriculture renamed the *Journal of Arboriculture* in 2006), *Arboricultural Journal* (1965 to present), *Cities and the Environment* (2008 to present), and *Urban Forestry & Urban Greening* (2002 to present)) were screened using the same terms for selection, since these were the journals most likely to have studies of interest (Hilbert et al., 2019). Only articles that had not been identified during the first part of the literature search were selected to eliminate duplication and eight articles were identified. The total number of articles (n = 841) were combined and duplicates (n = 42) removed. 799 articles were screened for applicability based on the title only and 458 articles were excluded from further review. The excluded articles were from Scopus (n = 294) and Web of Science (n = 194) as the backward chaining, forward chaining and in-depth search of the four urban forestry journals identified relevant articles as part of the process. The abstracts of the articles (n = 341) were screened for eligibility and a further 249 articles (Scopus (n = 193) and Web of Science (n = 56)) were excluded. The articles included (n = 92) in the structured literature review consisted of 38 articles from Scopus, 22 from Web of Science, 24 from forward and backward chaining and 8 from the additional journal search. These search results are summarised in the PRISMA flow chart in Figure 3.9. The final dataset consisted of 92 original articles published between 1980 and 2019.

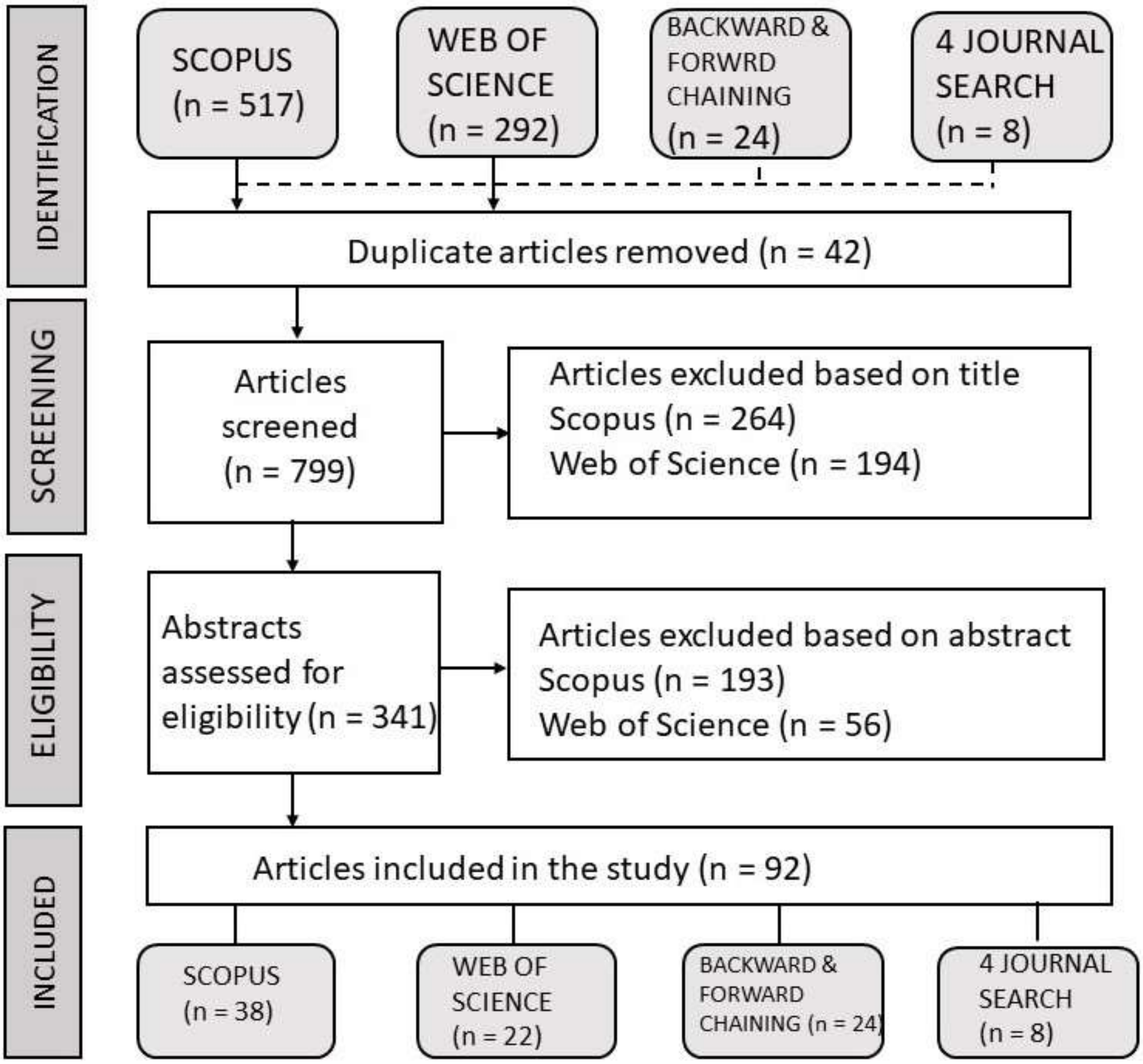


Figure 3.9: PRISMA flow diagram

3.5.5.2 Data extraction and analysis

In the literature review data were extracted and captured to provide information on:

- the main focus and research discourses in the articles
- bibliographic parameters of the studies: a) year of publication, b) publishing journal, and c) geographical region
- tree planting information (based on the inclusion criteria of the search) to identify aspects relating to the development and implementation of urban tree planting policies and strategies to guide tree planting and improve the survival of these trees.

Although the literature provided an academic understanding of the theoretical thinking with regard to a tree planting, it could not produce new, or validate existing, empirical insights (Mouton, 2004). Therefore, empirical findings from the current study were identified, evaluated and synthesised with the theoretical data that formed the basis of the tree planting to substantiate the theoretical data from the literature review. A tree planting guideline was developed to make an original contribution to the field of urban forestry in the CoJ. This study provided original information to guide future tree planting projects by identifying preferred locations for the placement of trees and a process based on previous studies, aiming to improve tree growth and survival and optimise the value added to the urban forest of the CoJ.

3.6 Ethical considerations

During the research, a concerted effort was made to ensure that the research process adhered to the values and principles expressed in the Unisa Policy on research ethics. The researcher adhered to all applicable legislation, the professional code of conduct, institutional guidelines and scientific standards relevant to the field of study.

The research was conducted with compliance to Unisa policies, in particular the Unisa College of Agriculture and Environmental Sciences (CAES) Research and Higher Degrees Committee. The research proposal was approved by the CAES Ethics Review Committee on 5 November 2015, prior to the commencement of the research, ethics reference number 2015/CAES/111.

3.7 Delineations and limitations of the study

This study was limited to the trees planted during the Greening Soweto Tree Planting project and the trees recorded on the verified tree register provided by JCPZ. This study did not deal with trees that were not planted as part of this project.

The incompleteness of the JCPZ tree register and unavailability of data explaining its incompleteness was a limitation in the location of the trees and subsequent data analysis.

Another limitation was the unavailability of a comprehensive tree inventory of the trees of the city, creating uncertainty, at times, of the locations of the trees of the project.

Service delivery protests limited the collection of data in Region G and parts of Regions A, E and F. Even though sufficient data were collected for the study, this is seen as a limitation as it is better to do a complete survey than a sample as was done for this study.

The short lifespan of the trees proved to be a limitation in determining growth or allometric relationships for these trees as the eight years of growth did not provide significant results.

Only the presence or absence of a pest or disease was recorded, and no attempt was made to identify any insect pest or disease; neither was the severity of the infestation indicated. This limited the analysis of the data with regard to pests and diseases.

CHAPTER 4
INVENTORY OF THE GREENING SOWETO PROJECT

4.1 Introduction

The results of the inventory of the 200 000 trees planted during the Greening Soweto Tree Planting (GSTP) project, also referred to as the Greening Soweto Legacy Project of the 2010 FIFA World Cup in the CoJ, are presented and discussed in this chapter. This includes an analysis of the inventory used for the study and verification of the number of trees planted, the species distribution and the number of existing trees that could be found. Reasons for missing trees are presented.

An in-depth analysis and verification of the data on the tree register of the trees planted during the project are given. This is followed by a description of the field survey results with regard to the identification of the tree species planted, the number and distribution of the existing trees and the species diversity of the project. Information is provided on the missing trees and the mortality and survival rates of the planting project. Mortality rate refers to the number of dead trees compared to those that are still alive (Elmes et al., 2018).

4.2 Tree register

The CoJ does not have a comprehensive tree inventory of the urban forest. This study was conducted using a tree register provided by JCPZ. This tree register will be referred to as the JCPZ tree register. The JCPZ tree register was created during the project and included all of the trees planted between 2005 and 2010. The data included in this tree register provided information on the year that the trees were planted, the suburb and street name where the trees were planted and the number of trees planted at each location. This data was arranged according to the seven administrative regions in the city, years of planting, locations (addresses) and number of trees and species. The data was used to verify the trees planted. Unfortunately, it did not provide the tree species for the years 2005 to 2009, but the tree species planted during 2010 were indicated. The JCPZ tree register also provided the number of trees verified as planted by JCPZ on 27 July 2011 and the total number of dead or missing trees on 27 July 2011.

The JCPZ tree register produced for this project is incomplete. For example, the lack of tree species names, GPS coordinates and valid locations or addresses limits the effective use of the register supplied by JCPZ. Due to this lack of information on the register, the verification of the trees can only be an estimation without a definitive verification. JCPZ indicated that due to limited space on pavements, numerous trees were given to residents to plant on their own properties (Johannesburg City Parks, n.d.), but no records were kept of the addresses of the residents. It is assumed that these trees were indicated as “various streets” on the tree register.

4.2.1 Results of the verification of the data on the tree register

According to the JCPZ tree register, 206 267 trees were originally planted (between 2005 and 2010) across the city, as part of the GSTP. This data was verified by JCPZ in July 2011, confirming 202 893 existing trees in the summary of the document, thereby establishing that 1.63% (n = 3 374) of the planted trees had not survived by 2011. The results of the recalculation of the tree planting and the verification numbers are presented in Table 4.1

However, this current study found that the number of trees verified as existing differs from the claim made by JCPZ in 2011. When the numbers of the missing trees indicated on the register were recalculated, the totals of this study differ from those provided by JCPZ in the summary of the document. The results from this study indicate that only 199 893 of the trees were existing in 2011, meaning that 3.2% (n = 6 608) of the trees did not survive. This is a difference of approximately 50% in the mortality rate of the trees by 2011, confirming that not all the trees planted had survived by 2011.

Results of this study indicate that of the 206 267 trees planted, fewer trees were planted during the period 2005-2006 and most were planted during the period 2007-2008. Subsequently, the least difference in the numbers of planted and verified trees by this study was from the period 2005-2006 and the largest difference was from the period 2008-2009. This shows that more trees planted in 2005-2006 survived than those planted in 2008-2009. However, the largest percentage mortality (7.13%) occurred in 2009-2010, even though that was not the year when the most trees were planted. The second highest percentage mortality (3.98%) occurred in 2008-2009, also not the year when the most trees were planted. The lowest percentage mortality was from 2005-2006 and the second lowest percentage mortality from 2007-2008. Most of the trees were planted in the period 2007-2008. Each year shows an increase in the percentage difference between the planted trees and the trees that were verified as absent on the register. In 2005-2006 the difference was 1.51%, which increased every year and eventually the difference was 7.13% in 2009-2010.

Table 4.1: Number of trees planted per year and verified (in 2011) as per JCPZ tree register

Year planted	**Number of trees planted**	**Trees verified in 2011**	**Variance**	**% difference**
2005 - 2006	23 973	23 611	362	1.51%
2007 - 2008	89 921	88 538	1 617	1.79%
2008 - 2009	62 155	59 681	2 474	3.98%
2009 - 2010	30 218	28 063	2 155	7.13%
Total	206 267	199 893	6 608	3.2% overall

The lowest number of trees were planted during the first two years of the project and this is probably due to JCPZ not being sufficiently prepared for the project or slow delivery of the external service provider or contractor. The numbers increased over the next three years, indicating sufficient processes in place to conduct the planting and reach the target by the expected date. The trees planted in 2005-2006 had a higher survival rate than those planted in any of the other years, and the trees planted in 2010 had the lowest survival rate. This may indicate attention to detail and adhering to planting specifications due to having fewer trees to plant during 2005-2006, which could possibly contribute to the low mortality rate. The pressure to complete the project and reach the targeted due date in 2010, in time for the start of the 2010 FIFA World Cup event, could have been a factor for the high mortality rate in 2010.

The verification conducted by applying the Google street view process and during site visits (refer to the methodology explained in section 3.5.1.3 of this study) confirmed that of the 206 267 trees planted, 122 039 were planted in locations with a verifiable address. This constitutes 59% of the trees on the tree register. The existence of the remaining 84 228 (41%) trees could not be verified as they were not linked to a region and they either had invalid or incomplete addresses, or were indicated on the tree register as "various streets", "local government institutions", "various parks", "various developments" or "various households". These trees could not be located for the purpose of the study and are presumed to be non-existent.

Scrutiny of the tree register revealed that trees were planted across the CoJ as presented in Figure 4.1. The largest number of trees with verifiable addresses were planted in Region C -

Western Johannesburg (31%; n = 38 010 trees), Region D – Greater Soweto (26%; n = 30 956 trees) and Region G – Southern Johannesburg (20%; n = 24 577 trees). The regions where the smallest numbers were planted were Region A - northern suburbs (9%; n = 11 159 trees), Region F - inner city (8%; n = 10 195 trees), Region B – north of the inner city (3%; n = 3 877 trees) and Region E – eastern part of the city (3%; n = 3 265 trees).

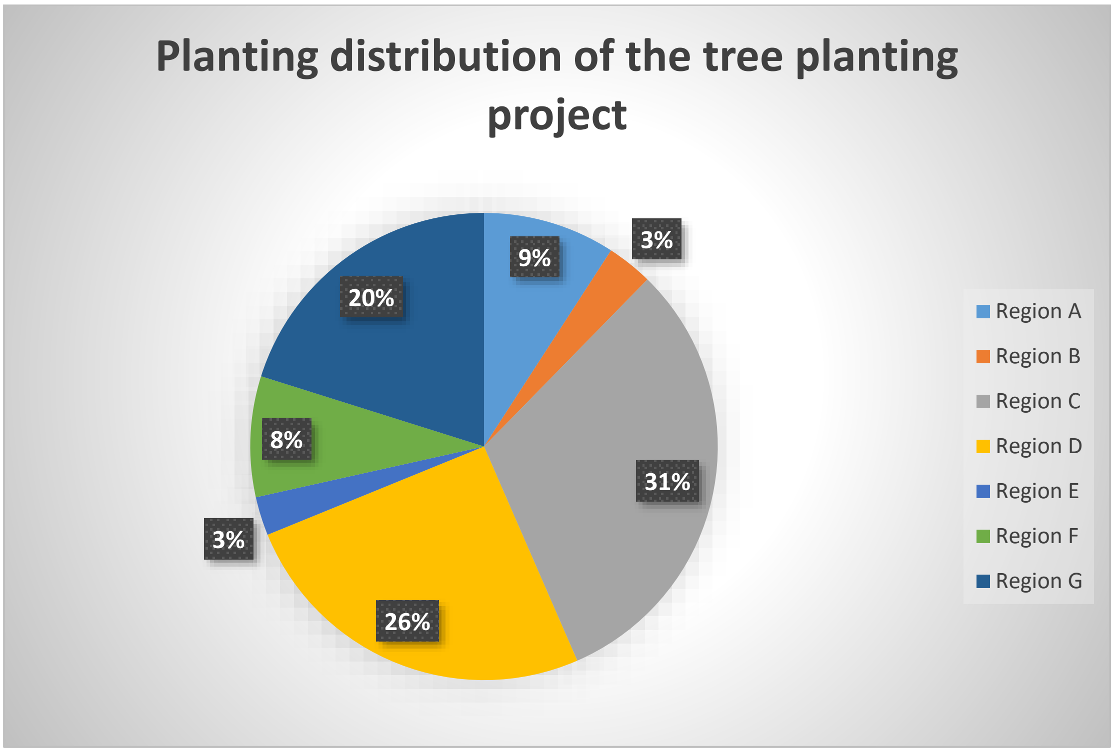


Figure 4.1: Verified information from JCPZ tree register of 122 039 trees with addresses, planted in seven regions in CoJ

The aim of the tree planting project was to focus on planting trees in previously disadvantaged areas (traditionally known as black and coloured townships), but trees were also planted in previously advantaged or traditionally white suburbs of the city. Figure 4.2 illustrates the distribution of the trees across advantaged and previously disadvantaged areas. Regions D and G are previously disadvantaged areas where 45.5% (n = 55 533) of the trees were planted. The other regions constitute a mixture of advantaged and disadvantaged areas in the same region. In Region A, 41.88% (n = 4 673), Region B, 12.22% (n = 473), Region C, 90.77% (n = 34 475), Region E, 70.56% (n = 2 304) and Region F, 60.54% (n = 6 172) of the trees were planted in previously disadvantaged areas in the regions. Therefore, it can be confirmed that 67.99% of the trees planted during the GSTP were planted in previously disadvantaged townships or areas.

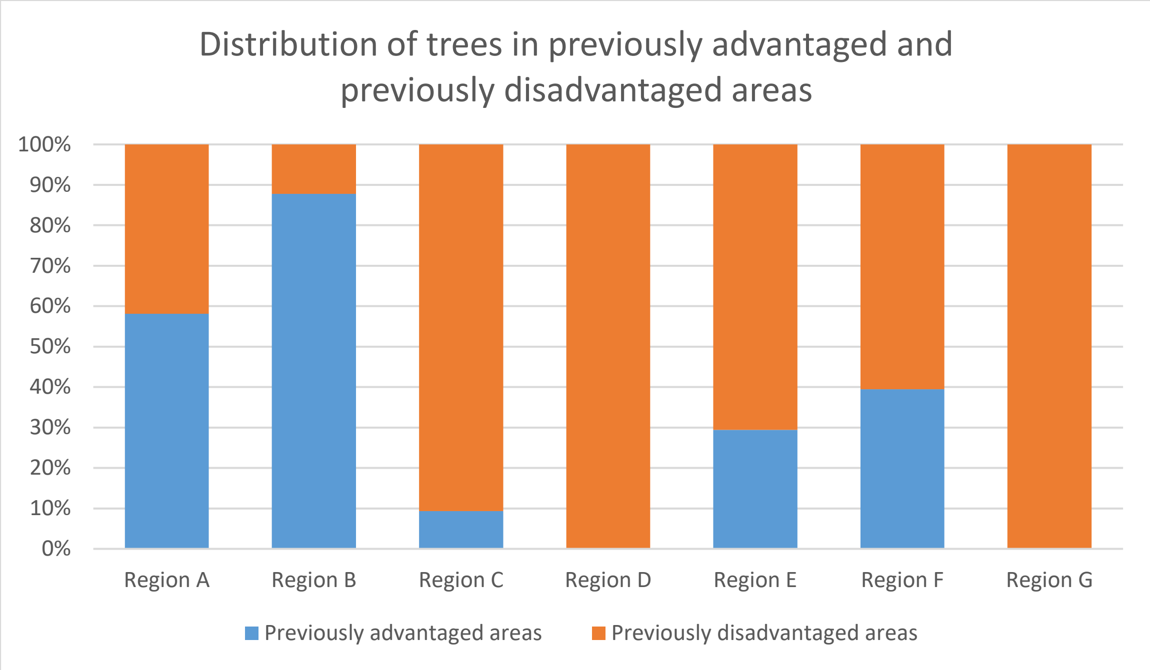


Figure 4.2: Distribution of trees in previously advantaged and previously disadvantaged areas

The results of this study dispute the statement of the city (JCPZ, 2012) that the trees were only planted in Soweto, as it can be seen (Figure 4.2) that the trees were planted across all seven administrative regions of the city. However, the previously disadvantaged areas, traditionally known to have the least trees, were the core focus areas during the tree planting. Regions D and G are previously disadvantaged areas and nearly half of the trees were planted in these regions. The other regions consist of a mixture of previously advantaged and disadvantaged areas, explaining the difference in distribution. The regions in the southern part of the city (Regions D, G and parts of Region F) are also known to have the least trees (Schäffler et al., 2013), explaining why Regions D and F received the most trees (together 46% of the trees). The northern area of the city (Regions A, B, E and sections of C and F) traditionally have the most established trees, which explains why the least number of trees were planted in Regions A, B, E and F (Figure 4.1). This confirms that the aim of the GSTP, namely to transform the previously disadvantaged regions in the southern part of the city, was reached by the completion of this project (JCPZ, 2012). The aim of this project differs from projects such as the Million Trees LA tree project in Los Angeles and the MillionTreesNYC tree project in New York City. The aim of both those projects was to plant trees to increase the environmental benefits associated with an urban forest (McPherson et al., 2011; Morani et al., 2011).

4.2.2 Results of assessing the tree locations

Figure 4.3 provides a visual representation of the results of this part of the study and represents the location distribution of the trees across the city. Table 4.2 presents the number of street trees and trees in other locations, per region. The results of the verification of the tree register indicate that, of the 122 039 trees planted in locations with a verifiable address, 76% (n = 92 104) of the trees were planted as street trees. The other locations constitute 6% (n = 7 528) planted in parks, 6% (n = 7 078) in shopping centres, 6% (n = 6 590) in riparian areas, 5% (n = 6 468) in cemeteries and 1% (n = 976) in schools and around sport complexes. Street tree planting was divided into 19.4% (n = 17 869) planted in the median and 80.6% (n = 74 235) planted on sidewalks.

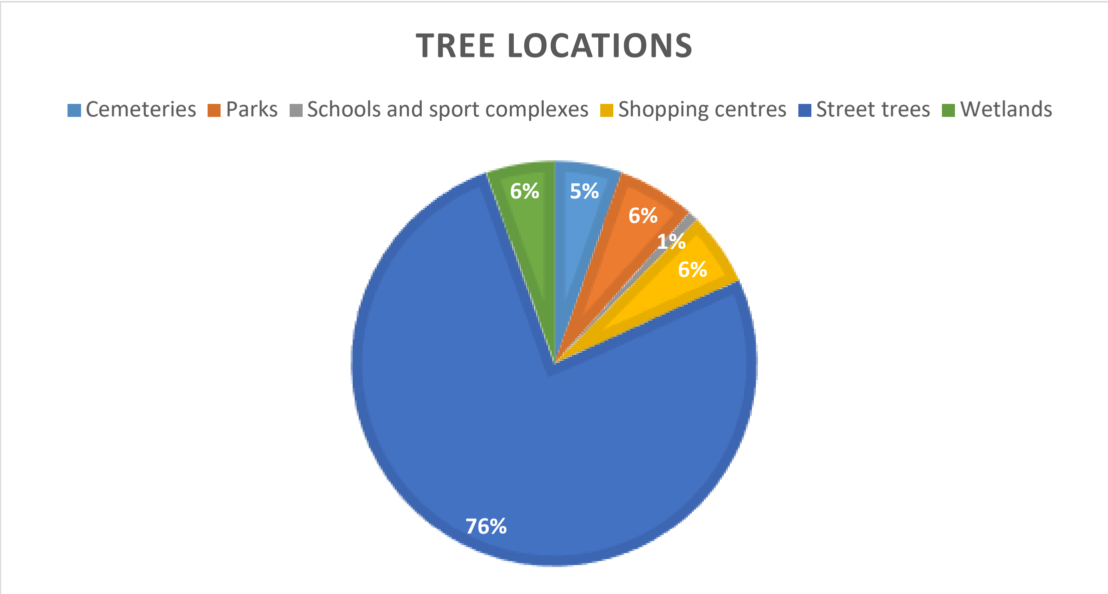


Figure 4.3: Locations of trees across city

Table 4.2 presents the numbers per region. In Region A, 87% (n = 9 725) of the trees were planted in streets and 13% (n = 1 434) in other areas consisting of 91% (n = 986) trees in parks, 3% (n = 148) in shopping centres and 6% (n = 300) in cemeteries. In Region B, 51% (n = 1 984) of the trees were planted in streets and 49% (n = 598) in other areas. The other areas consisted of 67% (n = 400) trees in a botanical garden and 33% (n = 198) in parks. In Region C, 94% (n = 35 680) of the trees were planted in streets and 6% (n = 2 330) were planted in other areas consisting of 63% (n = 1 474) trees in shopping centres and 37% (n = 856) in parks. In Region D, 45% (n = 13 857) of the trees were planted in streets and 55% (n = 17 099) in other areas. The other areas in Region D consisted of 12% (n = 2 505) in cemeteries, 6% (n = 1 057) in riparian areas, 6% (n = 1 070) in shopping centres and 76% (n = 4 632) in parks. In Region E, 87% (n = 2 850) of the trees were planted in streets and 17% (n = 415) in shopping centres. In Region F, 99% (n = 10 082) of the trees were planted in streets and 1% (n = 113) in parks. In Region G, 73% (n = 10 082) of the trees were planted in streets and 27% (n = 16 651) in other areas. These areas consisted of 80% (n = 5 313) in cemeteries and 20% (n = 1 388) in parks.

Table 4.2: Locations of trees per region

Region	Street trees	Other locations	Total
Region A	9 725	1 434	11 159
Region B	1 984	598	3 877
Region C	35 680	2 330	38 010
Region D	13 857	17 099	30 956
Region E	2 850	415	3 265
Region F	10 082	113	10 195
Region G	17 926	6 651	24 577
TOTAL	**92 104**	**28 640**	**122 039**

Three-quarters of the trees 75% (n = 92 104) were planted as street trees, indicating that street tree planting received priority as the project aimed to correct the apartheid era green infrastructure injustice manifesting in the lack of street tree planting in previously disadvantaged areas. In these areas, during the apartheid era, trees were planted mostly on the main arterials, as the sidewalk space of smaller streets was insufficient for tree growth (Buff, 2017). The GSTP also focused on developing parks with tree planting in previously disadvantaged areas. This was in line with the aim of the project – to convert the “dustbowls” and “landfill sites” into parks (JCPZ, 2012).

4.3 Results of the field survey

The results of the tree inventory utilising both Google street view and the physical site visit methodologies (systematic *in situ* field observations) are presented below. The individual species, their numbers and distribution were identified and are discussed.

4.3.1 Tree species of the project

Tree species identified during the field survey were mostly indigenous. The only exotic species identified were *Celtis sinensis* Willd. (English hackberry or Chinese elm), *Celtis orientalis* L. (pigeon wood) and *Liquidamber styraciflua* L. (sweetgum).

The indigenous trees comprised *Afrocarpus falcatus* (Thunb.) C.N. Page (Outeniqua yellowwood), previously known as *Podocarpus falcatus*, *Celtis africana* Burm.f. (white stinkwood), *Combretum erythrophyllum* (Burch.) Sond. (river bush willow), *Harpephyllum caffrum* Bernh. (wild plum), *Kiggelaria africana* L. (wild peach), *Olea europaea L. subsp. africana* (Miller) P.S. Green (wild olive), *Podocarpus henkelii* Stapf ex Dallim. & Jacks. (Henkel's yellowwood), *Podocarpus latifolius* (Thunb.) R.Br. ex Mirb. (real yellowwood), *Schotia brachypetala* Sond. (weeping boer-bean), *Searsia lancea* (L.f.) F.A. Barkley (karee), previously known as *Rhus lancea*, *Searsia pendulina* (Jacq.) Moffett (white karee), previously known as *Rhus pendulina, Senegalia galpinii* (Burtt Davy) Seigler & Ebinger (monkey thorn), previously known as *Acacia galpinii, Vachellia karroo* (Hayne) Banfi & Galasso (sweet thorn), previously known as *Acacia karroo, Vachellia sieberiana var. woodii* (Burtt Davy) Kyal. & Boatwr. (paperbark acacia), previously known as *Acacia sieberiana* var. *woodii.* Tree species names were verified using the Global Biodiversity Information facility (GBIF Secretariat, 2019).

The *Liquidamber* trees were only found at one location and were not included in this study. The *Celtis sinensis* trees were grouped together with the *Celtis africana* and *Celtis orientalis* trees due to hybridisation where many of the trees did not display clear characteristics of a specific species (Siebert, Struwig, Knoetze & Komape, 2018). JCPZ indicated that only *Celtis africana* trees were planted. Therefore, *Celtis africana* as a collective for the three species is reported on. The *Podocarpus henkelii* and *Podocarpus latifolius* were found together in one location with low numbers and it was decided to group the data of both *Podocarpus* species together for reporting purposes.

4.3.2 Number and distribution of existing tree species

Inventory was conducted in all the regions except Region E. The results from the field survey data in Regions C and D where the tree species and locations were verified were combined, analysed and compared with the number of trees originally planted, recorded and verified (July 2011) on the JCPZ tree register. The tree data provided information on the location (suburb and street name), identification of the tree species, number of existing trees, trees not on the tree register but found in the locations surveyed, trees not found per location and incorrect, incomplete or invalid addresses.

Of the 38 010 trees on the register for Region C, only 22.03% (n = 8 375) of the trees could be verified as existing. 87% (n = 25 801) of the trees could not be verified mainly due to addresses not provided and being indicated on the JCPZ register as “various streets” or “residential dwellings”. The remaining 12.94% (n = 3 803) consisted of a combination of fewer trees found in the streets or parks than were indicated on the tree register (6.67%; n = 1 978), trees indicated on the tree register as part of the project but confirmed as not being part of the project (3.44%; n = 1 021) and trees with incorrect addresses provided on the tree register (2.7%; n = 804). Finally, a small number (n = 31) of trees were identified at locations on the JCPZ tree register, but they were not part of the original verified JCPZ tree register. These trees were not taken into consideration for the remainder of this study.

The inventory of the JCPZ tree register in Region D identified 43.46% (n = 13 454) of the 30 956 trees on the register as existing. Of the 56% (n = 17 502) of the trees on the tree register that could not be verified, 59.59% (n = 10 430) were due to incorrect addresses, indicated on the register as various streets or residential dwellings, and 15.78% (n = 2 762) of the trees indicated on the JCPZ register (as part of the project) could not have been part of the project as these trees were visibly too old. The other 24.63% consisted of 9.21% (n = 1 613) trees not found at all, 8.797% (n = 4 056) with incorrect addresses, 3.17% (n = 555) fewer trees found in the location than was indicated on the tree register, or 3.08% (n = 540) unknown addresses. A total of 62 additional trees were identified in locations on the JCPZ register, even though they were not indicated on the tree register. These trees were also not included in the remainder of this study.

4.3.3 Estimates of number of trees

To estimate the net number of existing trees (2017/2018) of the entire project it was decided to use the best-case scenario (Region D = 43.46%) as a basis for the calculations. As this is an estimation, it was also decided to determine more than one possibility or scenario for the number of trees estimated to be alive. The number of trees originally planted, as per the tree register of JCPZ (n = 206 267) and the number of *in situ* verified trees (n = 122 039) were used for the calculation. When extrapolated to the entire project, using the number of trees with verifiable addresses (n = 122 039), the estimated existing trees for the entire GSTP project is 43.46% (n = 53 038) of 122 039 trees. The number of estimated existing trees (n =

89 644) indicates a loss of 56.54% (n = 116 623) of the originally planted trees (n = 206 267). When extrapolated, using the total number of originally planted trees (n = 206 267), the estimated existing trees for the entire GSTP project are 43.46% (n = 89 644) of the 206 267 trees on the JCPZ tree register. The loss of 56.53% (n = 116 623) trees indicates a mortality rate for the project of 56.53%.

To estimate the species distribution of the estimated existing trees across all the regions, a physical verification of a representative sample of the trees of the GSTP tree planting project was conducted. Tree species were identified and numbers of trees were counted. Most of the data was collected in Regions C (n = 1 044) and D (n = 1 410), but data was also collected from Regions A (n = 143), B (n = 71) and F (n = 238). The results of the numbers and respective percentage distributions of the different tree species in these regions are presented in Table 4.3.

Table 4.3: Tree species and numbers obtained from the physical verification process

Tree species	**Regions**						**% of the total**
	A	**B**	**C**	**D**	**F**	**TOTAL**	
Afrocarpus falcatus (AFFA)	0	0	0	23	23	46	1.58
Celtis africana (CEAF)	21	9	249	507	99	885	30.43
Combretum erythrophyllum (COER)	32	42	347	411	43	875	30.05
Harpephyllum caffrum (HACA)	0	0	10	0	0	10	0.34
Kiggelaria africana (KIAF)	0	0	0	14	0	14	0.48
Olea europaea subsp. africana (OLEU)	0	0	213	180	21	414	14.23
Podocarpus spp. (POSP)	0	20	0	0	0	20	0.68
*Schotia brachypetala (*SCBR)	0	0	0	0	21	21	0.72
Searsia lancea (SELA)	47	0	152	237	29	465	15.99
Searsia pendulina (SEPE)	1	0	73	14	0	88	3.12
Senegalia galpinii (SEGA)	42	0	0	0	0	42	1.44
Vachellia karroo (VAKA)	0	0	0	1	2	3	0.10
Vachellia sieberiana var. woodii (VACSI)	0	0	0	23	0	23	0.79
TOTAL	**143**	**71**	**1 044**	**1 410**	**238**	**2 906**	**100**

The geographic distribution and the different tree species inventoried are indicated on the map in Figure 4.4. Due to the small scale of the map, a dot does not indicate just one tree but a group of trees (n = 20) per species.

Data was collected from Regions A, B, C, D and F, but the GPS coordinates placed a few trees in Region E and Region G, as well. It must be noted that the data was collected according to the JCPZ tree register and the trees in Region E were indicated on the tree register as Region A and those in Region G were indicated on the tree register as Region D. Table 4.4 provides the number of trees planted and currently growig in the regions as illustrated in Figure 4.4. The difference in the numbers is as follows: Data was collected from one *S. pendulina* in Region A that was in Region E, and data was collected from 100 *C. africana* and 21 *S. brachypetala* trees in Region D that were in Region G.

The difference in the locations/regions on the map is due to the redefining of the regions subsequent to the planting of the trees. When the trees were planted, they were in Regions A and D. For the purpose of this study the tree locations on the tree register are used and reported on.

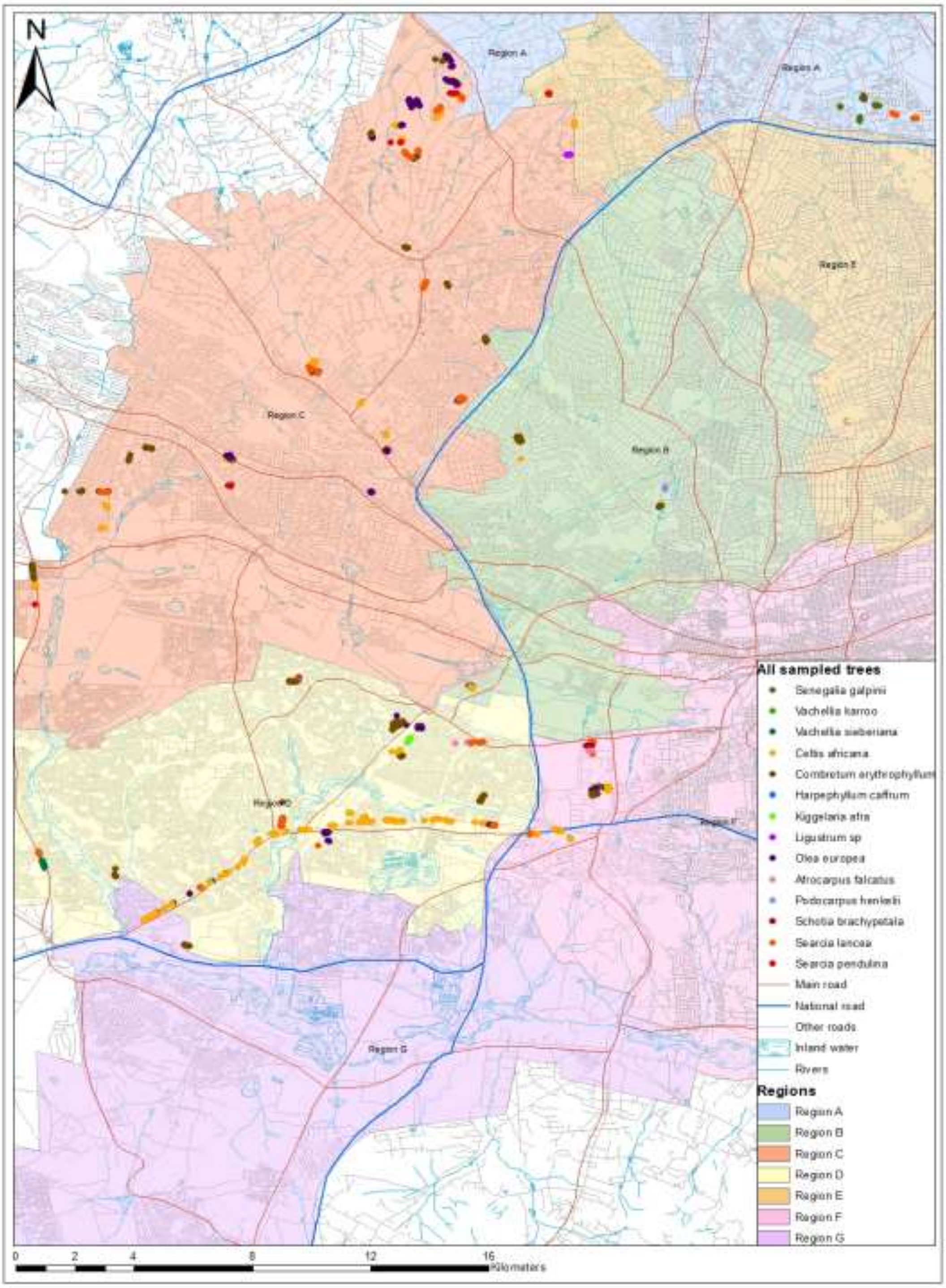


Figure 4.4: Geographic distribution of inventoried trees

Table 4.4: Number of trees for tree species planted in regions as illustrated in Figure 4.4

Tree species	**Regions**							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**TOTAL**
Afrocarpus falcatus (AFFA)	0	0	0	23	0	23	0	46
Celtis africana (CEAF)	21	9	249	407	0	99	100	885
Combretum erythrophyllum (COER)	32	42	347	411	0	43	0	875
Harpephyllum caffrum (HACA)	0	0	10	0	0	0	0	10
Kiggelaria africana (KIAF)	0	0	0	14	0	0	0	14
Olea europaea subsp. africana (OLEU)	0	0	213	180	0	21	0	414
Podocarpus spp. (POSP)	0	20	0	0	0	0	0	20
*Schotia brachypetala (*SCBR)	0	0	0	0	0	0	21	21
Searsia lancea (SELA)	47	0	152	237	0	29	0	465
Searsia pendulina (SEPE)	0	0	73	14	1	0	0	88
Senegalia galpinii (SEGA)	42	0	0	0	0	0	0	42
Vachellia karroo (VAKA)	0	0	0	1	0	2	0	3
Vachellia sieberiana var. woodii (VACSI)	0	0	0	23	0	0	0	23
TOTAL	**142**	**71**	**1 044**	**1 289**	**1**	**238**	**121**	**2 906**

The physical verification process identified the tree species and the location of the tree. The tree location identified the street name where the tree was found and distinguished between locating the tree on the sidewalk, median or in a park. The cross streets for both the street and park were included for future reference. The diameter at ground level (DGL) and the diameter at breast height (DBH) were measured and linked to the data collection date. GPS coordinates were taken for each tree and an indication of the land use and land cover where the tree was planted was also noted as well as pest and disease presence, maintenance needs, any conflict with the built environment and the human influence surrounding the tree. Using this information, an attempt was made to compile an updated tree inventory. An example of this inventory is provided in Table 4.5 and consists of the following information: Tree code and species name, tree identification number, street address including a suburb, an indication if the tree was planted in a street or park, date of planting, GPS coordinates, DGL and DBH measurements, number of stems, tree condition, maintenance required, land use and land cover surrounding the tree, pest and disease presence, conflict created by the tree and a digital photograph identification.

Table 4.5: Example of section of completed tree inventory for the project

Scientific name of the tree species and genera		Tree identification number	Date of data collection	Street address including the suburb		Park or street tree	The date/year when the tree was planted	GPS coordinates (longitude and latitude)		DGL mm		DBH mm		Number of stems	Condition of the tree	Maintenance requirements	Land use where the tree is planted	Land cover directly surrounding the tree	Pests and disease presence	Conflict of the tree with the built environment	Digital Photo ID
Tree code	Scientific name			Street	Suburb			longitude	latitude	circumference	diameter	circumference	diameter		*01 - 04	*01 - 04	*01 - 06	*01 - 06	*01 - 04	*01 - 05	
COER	Combretum erythrophyllum	1	23/03/2017	Rivonia Road,	Sunning hill	Street	2007	2601654	2803747	240	76.43	130	41.40	1	2	3	1	1	1	1	91
COER	Combretum erythrophyllum	2	23/03/2017	Rivonia Road,	Sunning hill	Street	2007	2601656	2803747	221	70.38	169	53.82	3	2	3	1	1	1	2	92
COER	Combretum erythrophyllum	3	23/03/2017	Rivonia Road,	Sunning hill	Street	2007	2601661	2803747	260	82.80	205	65.29	2	1	3	1	1	1	2	93
COER	Combretum erythrophyllum	4	23/03/2017	Rivonia Road,	Sunning hill	Street	2007	2601662	2803745	204	64.97	0	0.00	1	1	3	1	1	1	2	94
COER	Combretum erythrophyllum	5	23/03/2017	Rivonia Road,	Sunning hill	Street	2007	2601662	2803742	180	57.32	140	44.59	1	3	3	1	1	1	1	95
COER	Combretum erythrophyllum	6	23/03/2017	Rivonia Road,	Sunning hill	Street	2007	2601668	2803745	212	67.52	183	58.28	4	3	2	2	1	1	1	97
COER	Combretum erythrophyllum	7	23/03/2017	Tana Rd	Sunning hill	Park	2006	2601669	2803751	182	57.96	98	31.21	1	1	3	2	1	1	1	124
COER	Combretum erythrophyllum	8	23/03/2017	Tana Rd	Sunning hill	Park	2006	2601697	2803753	160	50.96	95	30.25	2	4	3	2	1	1	1	125
COER	Combretum erythrophyllum	9	23/03/2017	Tana Rd	Sunning hill	Park	2006	2601696	2803750	176	56.05	101	32.17	3	4	4	2	1	1	1	126
COER	Combretum erythrophyllum	10	23/03/2017	Tana Rd	Sunning hill	Park	2006	2601694	2803748	75	23.89	0	0.00	1	1	3	2	1	1	1	127

To estimate the numbers of existing (2017/2018) tree species for the GSTP, the percentage distribution seen in Table 4.3 for the tree species found during the data collection was used and calculated as a percentage of the estimated existing (n = 89 644) number of trees.

The number of indigenous tree species found and extrapolated to the number of estimated trees surviving and growing are presented in Figure 4.5. 13 indigenous tree species were found, and 90.7% of the trees planted during the project consist of four tree species: *Celtis africana* (30.4%; n = 27 282), *Combretum erythrophyllum* (30.1%; n = 26 943), *Searsia lancea* (16%; n = 14 334) and *Olea europaea* subsp. a*fricana* (14.2%; n = 12 762). Two species, *Celtis africana* (30.4%; n = 27 282) and *Combretum erythrophyllum* (30.1%; n = 26 943), constituted 60% of the trees that were inventoried. The remaining 9.3% consisted of nine species: *Searsia pendulina* (3.1%; n = 2 805), *Afrocarpus falcatus* (1.6%; n = 1 418), *Senegalia galpinii* (1.4%; n = 1 295)*, Vachellia sieberiana* var. *woodii* (0.8%; n = 709), *Schotia brachypetala* (0.72%; n = 647), *Podocarpus* spp*.* (0.69%; n = 617), *Kiggelaria africana* (0.5%; n = 432), *Harpephyllum caffrum* (0.3%; n = 308) and *Vachellia karroo* (0.01%; n = 92).

The extrapolated number of estimated trees that survived and are growing per region and the results of the estimated number of trees are presented in Table 4.6. These numbers are based on the distribution of the trees in the JCPZ tree register as presented in Figure 4.1. The differences in the numbers of the trees are due to the high mortality and the number of trees estimated to be “missing”. Information on the “missing” trees is presented in section 4.3.5 of this chapter.

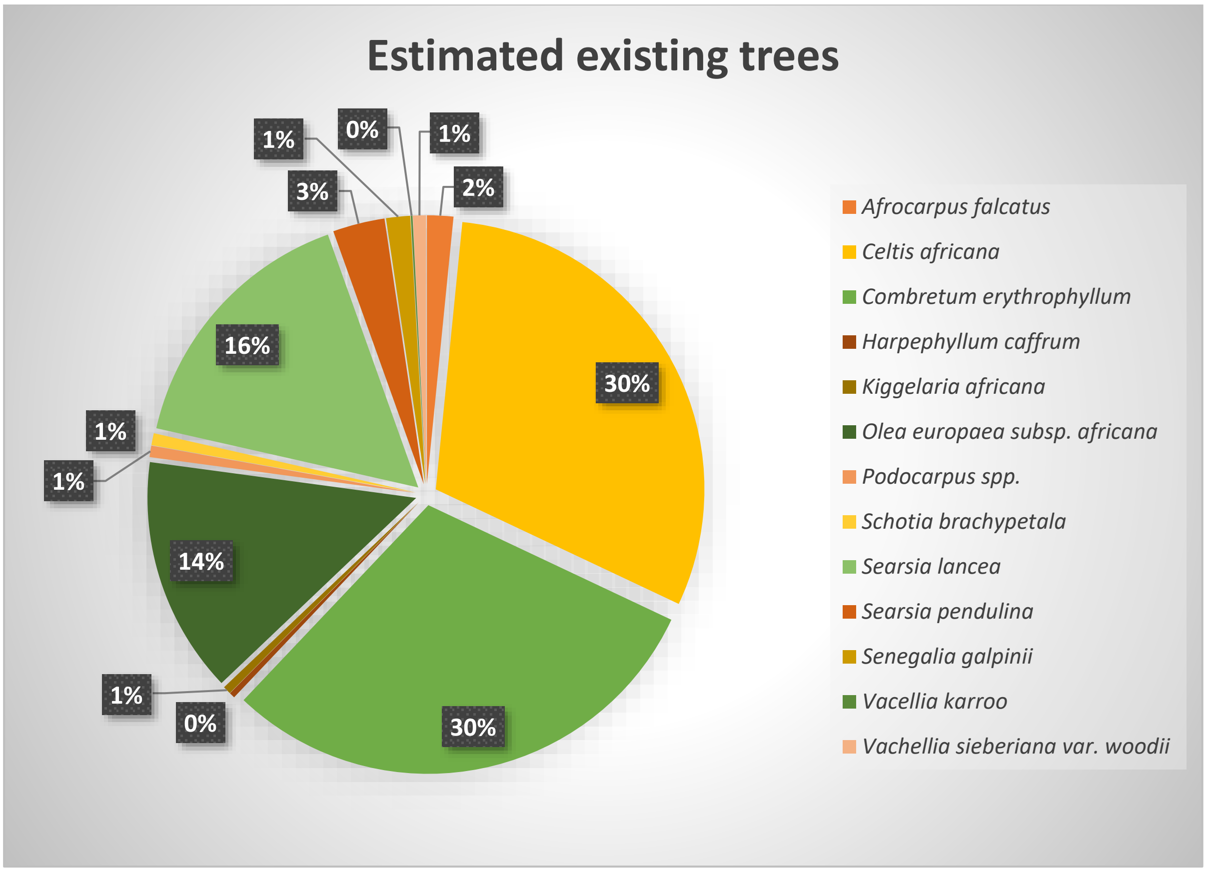


Figure 4.5: Distribution of tree species

Table 4.6: Extrapolated number of estimated trees that survived and are growing, per region

Regions	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Percentage distribution	9%	3%	31%	26%	20%	8%	3%
Tree number on the tree register	11 159	3 877	38 010	30 956	3 265	10 195	24 577
Estimated existing number of trees	8 068	2 689	27 790	23 307	17 929	7 172	2 689

In the table above, the distribution per region, determined from the JCPZ tree register and the tree numbers on the tree register, is displayed.

4.3.4 Species diversity

When applying the 10:20:30 rule (Santamour, 1990) to the GSTP, it is clear that four species each constitute more than 10% of the trees in the project (*C. africana* 30.43%, *C. erythrophyllum* 30.05%, *S. lancea* 15.99% and *O. europaea subsp. africana* 14.23%). Santamour (1990) recommends that not more than 10% of the trees be of a single species.

S. lancea (15.99%) and *S. pendulina* (3.12%) constitute 19.11%, which is close to the guideline that not more than 20% of the trees should be of a single genus. *V. karroo* (0.10%) and *V. sieberiana var. woodii* (0.79%) constitute 0.89% which is much lower than the guideline provided for a single species and therefore acceptable. The families represented in this study with more than 30% distribution, due to the large numbers of single species, are Ulmaceae (*C. africana* 30.43%) and Combretaceae (*C. erythrophyllum* 30.05%). The family with the most species (n = 4) represented in the study are Fabaceae, but due to their low numbers (*S. brachypetala* (0.72%), ***S.*** *galpinii* (1.44%), *V. karroo* (0.10%) and *V. sieberiana var. woodii* (0.79%) in the study, constitute only 3.05% of the trees. Therefore, the species diversity of this study was limited. This should be cause for alarm. The importance of species diversity is well known, since it minimises the risk of catastrophic loss resulting from insects, disease or other harmful agents (McPherson & Rowntree, 1987).

According to city council officials, *C. africana, C. erythrophyllum* and *S. lancea* tree species are well adapted to the urban conditions in Johannesburg and are preferred by the horticulturists responsible for the management of this city's trees (Chokoe, 2017). Species diversity was not one of the aims of the tree planting project but should always be a priority when projects involving large numbers of trees are planned.

4.3.5 Missing trees

Based on the Google street view process and the subsequent site visit observations, it was evident that some of the trees that were planted during the GSTP were either dead, absent, seriously damaged or consisted mainly of coppice growth and these are referred to as "missing trees". *V. karroo* and *H. caffrum* did not have any missing trees. Most of the missing trees were identified as *C. erythrophyllum* (31.8% of the missing trees, n = 142), and constituted 16.2% of the trees in the study (n = 875). 86 (19.2%) of the missing trees were *Searsia lancea*, which is 18.5% of the trees in the study (n = 465). 83 (18.6%) of the *S. pendulina* trees were missing, which is94.3% of the trees in the study (n = 88) and 67 (15%) of the missing trees in the study were *O. europaea subsp. africana,* i.e. 16.2% of the trees in the study (n = 414). 51 (11.4%) of the missing trees were *C. africana*, which is 5.8% of the trees in the study (n = 885). Fewer than 10 trees per species were missing from the following tree species: *A. falcatus* 1 (1.8%), *V. sieberiana var. Woodii* 3 (0.7%), *S. galpinii* 1 (0.2%) and *S. brachteata* 1 (0.2%).

4.3.6 Missing tree categories

Some of the trees that were planted during the GSTP were either dead, absent, seriously damaged or consisted mainly of coppice growth. A tree was classified as a "dead tree" (Figure 4.6) if no living leaves were found on the tree, the branches were clearly dead and dried out, but the tree was still present in the planting location. A tree was classified as "absent" (Figure

4.7) if evidence of a previously planted tree in the form of an empty tree bowl was found and a "dead stump" (Figure 4.8) was classified as such when there was only a stump or broken tree present. The presence of coppice was classified in two categories. "Coppice only" (Figure 4.9) described a tree that was allowed to sprout and grow so much coppice that no main stem existed. This was observed where the main stem was either dead or broken and had been removed. The second category of coppice was called "dead tree with coppice" (Figure 4.10) and indicated a present but dead main stem with coppice surrounding the dead tree.

Figure 4.6: Dead tree

Figure 4.7: Absent tree

Figure 4.8: Dead stump

Figure 4.9: Coppice only

Figure 4.101: Dead tree with coppice growth

The results of the missing trees per species per category are displayed in Figure 4.11. Most of the missing trees were *C. erythrophyllum* (31.8%; n = 142), *S. lancea* (19.2%; n = 86), *S. pendulina* (18.6%; n = 83) and *C. africana* (11.4%; n = 51) species. The remaining 4% of missing trees were distributed among five species in small percentages. The distribution of the categories of missing trees per species is presented in Figure 4.11.

Kiggelaria africana, S. galipinii, P. falcatus, *Podocarpus* species and *S. brachypetala* had one category of missing tree each and *V. sieberiana var. woodii* had two categories of missing trees. *Searsia pendulina* had four different categories of missing trees and the other four species, *C. africana, O. europaea* subsp. *africana*, *S. lancea* and *C. erythrophyllum,* each had five categories of missing trees.

Results of the five trees with the most categories of missing trees are discussed. The percentages relative to the number (n = 447) of missing trees are given. The missing trees of *C. erythrophyllum* (n = 142) constituted 24.38% (n = 109) coppice growth only, 3.57% (n = 16) absent trees, 1.78% (n = 8) stumps with coppice, 1.11% (n = 5) dead trees and 0.89% (n = 4) dead stumps. The missing trees of *S. lancea* (n = 86) amounted to 7.06% (n = 34) absent trees, 7.38% (n = 33) coppice only, 2.46% (n = 11) dead trees, 1.34% (n = 6) stumps with coppice and 0.47% (n = 2) dead stumps. The missing trees of *S. pendulina* (n = 83) constituted 8.94% (n = 40) coppice only, 8.27% (n = 37) absent trees, 1.11% (n = 5) dead trees and 0.447% (n = 2) stump with coppice. The missing trees of *O. europaea* subsp. *africana* (n = 67) constituted 7.61% (n = 34) absent trees, 3.13% (n = 14) coppice only, 2.23% (n = 10) dead trees, 1.79% (n = 8) stumps with coppice and 0.22% (n = 1) dead stumps. The missing trees of *C. africana* (n = 51) constituted 3.8% (n = 17) dead trees, 3.35% (n = 15) for both absent trees and coppice only, 0.67% (n = 3) stumps with coppice and 0.22% (n = 1) dead stumps.

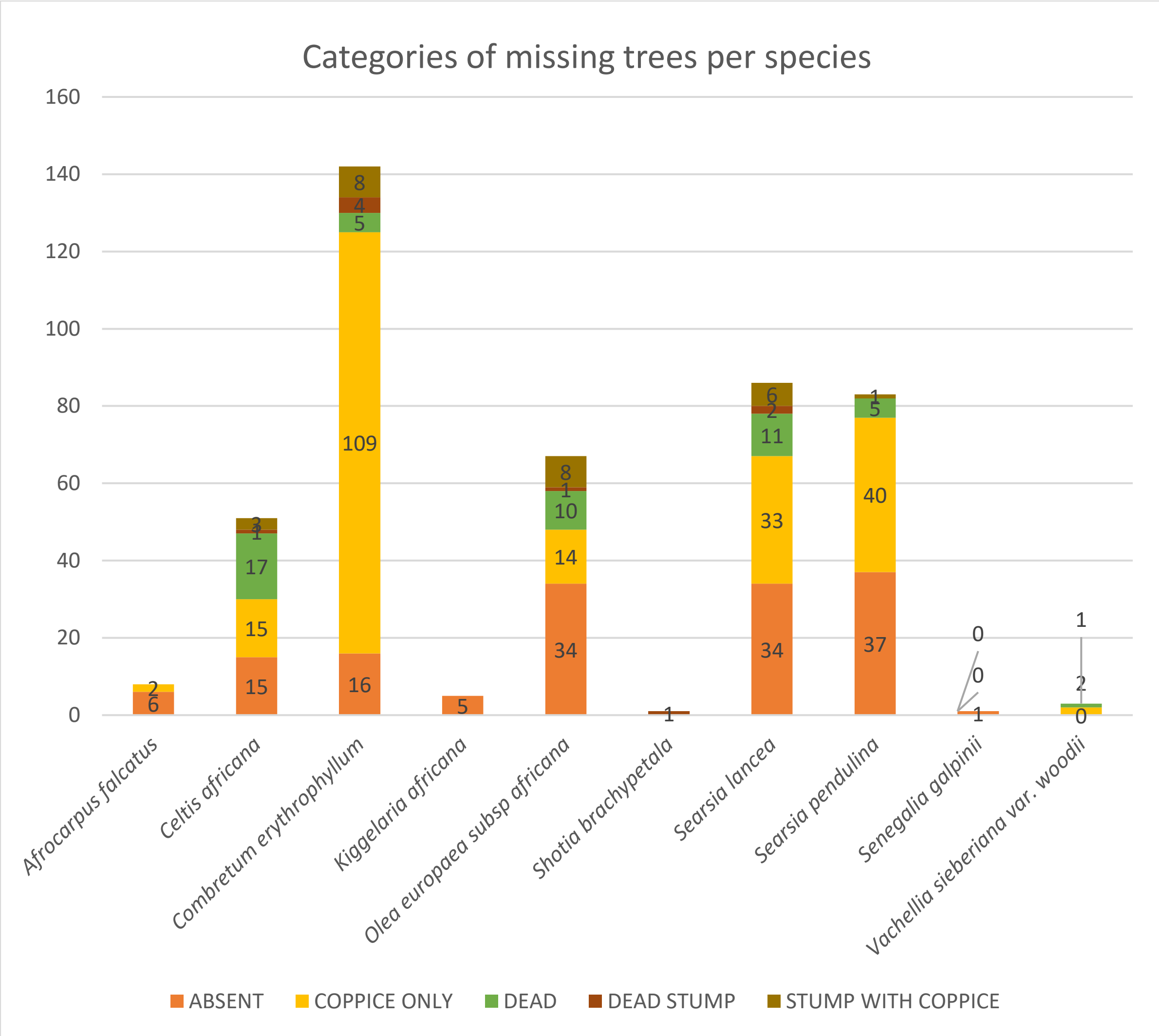


Figure 4.11: Categories of missing trees

The distribution of the categories of missing trees (Figure 4.12) was attributed mostly to absent trees (33.1%; n = 148) and coppice only 48.1% (n = 215). The remaining 18.5% consisted of dead trees (11%; n = 49), stump with coppice (5.8%; n = 26) and dead stumps (2%; n = 9).

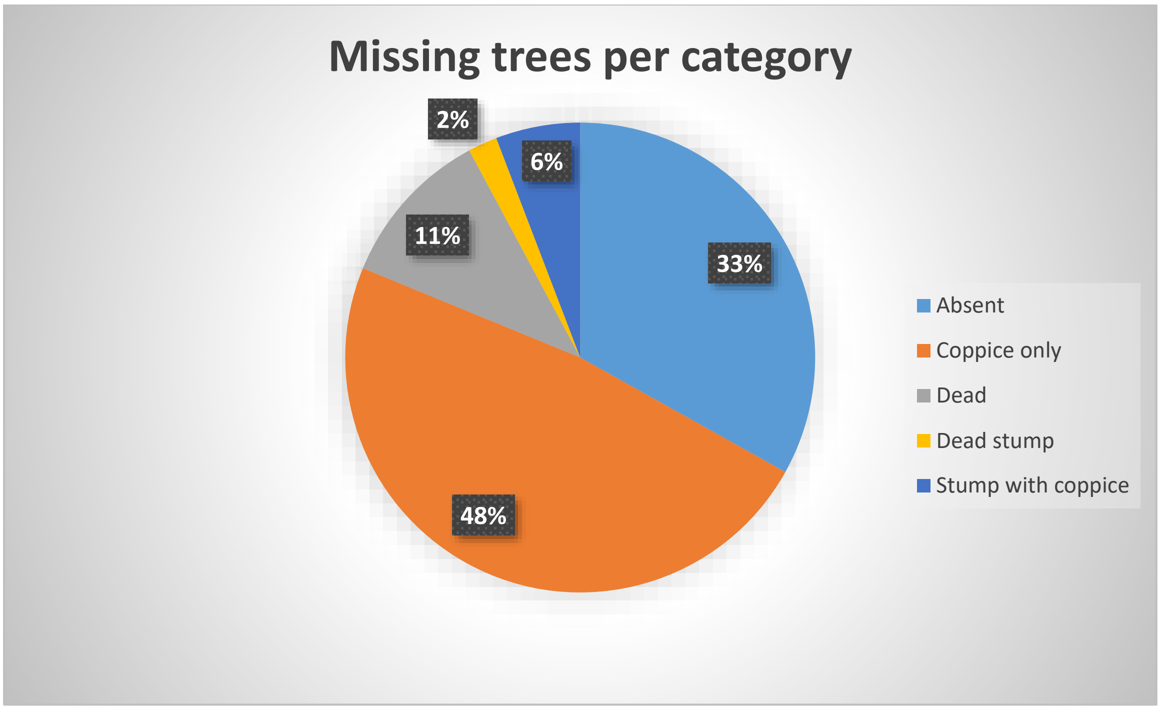


Figure 4.12: Different types of missing trees

The results from the different species were combined and extrapolated to estimate the total number of missing trees for each category for the project (Figure 4.12 and Table 4.7). Of the 2 906 trees in the field survey, 15.37% (n = 447) were missing. Therefore, if it is assumed that this trend is maintained throughout the project, 15.37% of the estimated existing number of trees (n = 89 644) result in 13 778 missing trees overall. This number reduces the estimated existing trees for the tree planting project to 75 866. Using the overall missing tree number (n = 13 778), the estimated missing trees per category were determined. Of the missing trees related to coppice growth, i.e. 54% (n = 7 440), 48% (n = 6 614) were categorised as coppice only and 6% (n = 826) as dead tree with coppice. 33% (n = 4 547) of the missing trees were categorised as absent and 11% (n = 1 516) as dead but still standing where they were planted. 2% (n = 275) of the missing trees were dead stumps still standing where they were planted.

Table 4.7: Post-extrapolation net results of missing trees per category

Missing tree categories	Percentage distribution	Tree quantities
Absent	33	4 547
Coppice only	48	6 614
Dead	11	1 516
Dead stump	2	275
Dead tree with coppice	6	826
TOTAL	**100**	**13 778**

The missing trees are dominated by the presence of coppice growth. Coppice growth is shoots or new growth arising from dormant adventitious buds near the base or stump of a tree. When the main stem is cut down or broken, the dormancy of the adventitious buds is broken, and the buds develop into small upward growing shoots. It is often used in reforestation practices in natural regeneration of some hardwood forest species and forms part of woodland management (Pommerening & Murphy, 2004) but coppice is unacceptable when these species are used as functional street trees. A typical urban tree is a woody perennial of considerable height with a single stem or trunk and a distinct crown formed by lateral branches forming at some height from the ground (Roy et al., 2012).

Combretum erythrophyllum was found to have an increased tendency to form coppice growth. The high presence of coppice growth in *S. pendulina* (40.65% of the trees in the study) highlights a concern with the utilisation of this species in an urban environment as park and street trees. The 12.47% (n = 109) coppice growth found in *C. erythrophyllum* trees indicates a lack of maintenance. When the coppice results of *C. erythrophyllum* are compared with those of *C. africana* (1.69%; n = 15), it is apparent that *C. erythrophyllum* and *S. pendulina* tend to form more coppice growth than *C. africana* or any of the other tree species. Maintaining urban trees' shape requires constant pruning of coppice growth, which increases the costs of utilising these trees in an urban forest.

The "absent" category of the missing trees refers to evidence of a previously planted tree in the form of an empty tree bowl. 28% of the missing trees were found to be absent. The period of their absence could not be determined. As the tree register for this project is incomplete, the verification conducted in 2011 did not indicate which trees were not found and did not provide reasons for the difference in the number of trees. Therefore, a time frame for the absent trees cannot be confirmed. Unfortunately, during the field survey very few replacement trees were identified.

Definitive reasons for the occurrence of missing trees could not be determined. With the high percentage of the trees planted in previously disadvantaged areas with lower socio-economic conditions and associated unemployment, these trees were exposed to high pedestrian activity as residents spend time in the neighbourhood while searching for job opportunities. This may have a negative influence on the survival of the trees (Nowak et al., 1990). Various authors state that tree losses could be attributed to possibilities such as vandalism (Pauleit et al., 2002; Lu et al., 2010; Richardson & Shackleton, 2014), lack of maintenance (Vogt, Hauer & Fischer, 2015), poor maintenance and design practices (Gilbertson & Bradshaw, 1990) and incorrect choice of tree species (Conway & Vander Vecht, 2015). Roman et al. (2014a) deduce that small trees are more susceptible to stress, injury, inadequate maintenance and vandalism. This provides an excellent opportunity for further research to determine the reasons for the missing trees of the project.

4.3.7 Mortality and survival

This study cannot determine a certain mortality and survival rate, but it can provide results on trees that could be verified as existing and still growing. If it is assumed that all the trees that could not be verified are dead, the mortality rate of this project is 67.25%. By adding the trees that were identified as missing during the field survey, the mortality rate increases to 72%. This is a concern as literature highlights other tree planting projects with lower mortality as the norm.

Gilbertson and Bradshaw (1990) monitored a new tree planting project in the inner-city area of Liverpool and identified that nearly 39% of trees died within five years of planting, relating this mostly to poor maintenance and design practices. Roman et al. (2014a) observed mortality rates of up to 27.1% for newly planted trees in Oakland in California, USA, over a five-year period (2007-2011) after planting. In contrast, the annual survival rate of street trees in the city of Philadelphia, USA, was 94.9–96.5%, with a corresponding annual mortality rate of 3.5–5.1% (Roman & Scatena, 2011), which is within the range of typical annual street tree mortality (3.5–5.1 %) for mature street trees (Roman et al., 2014b).

4.4 A framework for an inventory

To compile a framework for an inventory for the trees of the GSTP, existing international tree inventories were consulted and combined with results from this study to customise the inventory for use in the CoJ, South Africa.

Östberg (2013) used the Delphi method to provide a list of tree inventory parameters from international inventories and used city officials, academics and arborists to rate their importance. The study initially revealed 148 tree inventory parameters and subsequent to the rating of the parameters, identified 25 parameters as it reflects the number of parameters in most urban tree inventories. He concluded that it is important to include a parameter for a specific reason and to only include parameters if the parameter data is easily collected. The parameters suggested by Östberg are presented in Table 4.8, together with a reason for including the parameter.

Table 4.8: Tree inventory parameters (Adapted from Östberg (2013)

Tree inventory parameter	**Motivation**
Scientific name of the tree species and genera	Identification purposes
Date of latest inventory	Tracks the data
Coordinates	Identifies the tree location
Date of planting	Determines the age of the tree
Identification number	Links the tree to the database, for identification purposes
Street or park trees	Identifies location
Vitality	Condition of the tree to anticipate longevity or corrective action required
Hazard class	Identification of hazard to the surrounding environment and seriousness of the hazard
Category of care	Identifies care required
Conservation value	Conservation status of tree
Street or park address	Identifies the location of the tree
Owner	Public or private tree
Stem circumference measurements	Determines the size of the tree; can be used to determine growth with future circumference measurements
Age class	Provides data to plan maintenance and replacement
Type of constructed planting site	Determines influence of construction on growth
Maintenance requested	Tree management data
Proposed maintenance measures	Indication if any pruning, fertilization, watering etc. might be needed
Name of disease or pest	Identifies risk, provides information for maintenance operations required

Presence of stem protection	Maintenance requirements, can influence vitality or condition of tree
Soil protection around the tree	Maintenance requirements, can influence vitality or condition of tree
Comments on hazard and damages	Informs maintenance plans to prevent hazardous conditions created by the trees
Date of registration in the database	Referencing purposes
Date of update in the database	Provides a time frame for growth determination and maintenance requirements

Some of the parameters on this list in Table 4.8 are too elaborate to include in a South African inventory at this time requiring further research and therefore dd not form part of the proposed inventory.

Other parameters on the list by Östberg (2013) that are of interest to this study and relevant to South Africa are pruning, protection value, mechanical damage, conflict with infrastructure, maintenance programme, groundcover around the tree trunk, name of person collecting the data, number of trunks, crown diameter, need for protective measures to shield the tree from damage, disturbance on the site, stem protection or repair required, stem height, presence or tree support, tree height, location, stem diameter at 1.3 m, function on site, estimated lifetime, diseases and pests in the vicinity, species suitability for the site, land use and crown height.

From the data collected during the site visit part of the study, the following parameters were identified to form part of a tree inventory: tree species code, date of data collection, names of people collecting the data, year of planting, suburb and the street address, DGL and DBH measurements, GPS coordinates (longitude and latitude) for each tree and an indication of the planting site, either as street or park tree. The land use and land cover where the tree was planted, presence of pests and diseases, maintenance needs, possible conflict of the tree with the built environment and the human influence surrounding the tree concludes the information (Table 4.8).

It is foreseen that should a geographically representative tree inventory be initiated in the CoJ, a “classic” single-tree field survey method will be followed. Östberg (2013) refers to a “classic” single-tree field survey as a survey where people conduct direct measurements and visual inspections on the ground. This type of survey is labour-intensive and generally limited to public trees, as it is often difficult to access trees on private land (Nowak et al., 2008). Alternative tree inventory methods such as i-Tree, used extensively in US cities, are currently not available for South African conditions and tree species. Satellite- and aeroplane-supported methods (Ardila, Bijker, Tolpekin & Stein, 2012), ground scanning and digital photography (Clark, Schmoldt & Araman, 2000) have also been used internationally; however, data processing methods limit the reliability of this data at present (Östberg, 2013).

It is important that the data of the tree inventory parameters of the suggested inventory framework (presented in Table 4.9) can be collected during field surveys. Therefore, the classic single-tree field survey method is deemed as the most appropriate for South African circumstances. Each of the inventory parameters contributes to the inventory in one way or another and the parameter indicators in the second column of Table 4.9 provide information on what data the survey will comprise.

Table 4.9: Tree inventory parameters and parameter indicators

Tree inventory parameters	**Parameter indicator collected during field surveys**
Scientific name of the tree species	Genus and species name
Tree identification number	Six-digit number
Date of data collection	dd/mm/yyyy
Street address including the suburb	Street name, suburb name
Park or street tree	Park/street
The date/year when the tree was planted	dd/mm/yyyy
GPS coordinates (longitude and latitude)	0° 0' 0'' N 0° 0' 0'' E
DGL	Measurement in circumference (mm) and converted to diameter (mm)
DBH	Measurement in circumference (mm) and converted to diameter (mm)
Number of stems	1-5 (maximum of 5)
Condition of the tree (damage, vitality, risk)	01 Excellent 02 Good 03 Not acceptable 04 To be removed
Maintenance requirements	01 None required

	02 Pruning 03 Staking 04 Coppice removal
Land use where the tree is planted (residential, industrial etc.)	01 Residential 02 Industrial 03 Green open space 04 Commercial 05 Institutional 06 Vacant
Land cover directly surrounding the tree (maintained lawn, bare soil etc.)	01 Maintained lawn 02 Unmaintained grass 03 Bare soil 04 Hard landscaping 05 Flower bed 06 Paving
Pests and disease presence	01 None present 02 Insects 03 Diseases 04 Other
Conflict of the tree with the built environment	01 None 02 Road 03 Kerb 04 Overhead structures 05 Buildings
Digital photograph identification number	Six-digit number linked to a date dd/mm/yy

This inventory framework (Table 4.9) can replace the existing JCPZ tree register, but will require a complete tree survey of all the trees that were planted. The inventory will provide a valuable resource for the determination of the benefits and value of the asset in future. This framework may also be used for the entire urban forest of the CoJ when the city decides to embark on a quantification of this resource.

4.5 Discussion

The value of a comprehensive tree inventory in the urban environment has been known for years. In 1997, Olig and Miller stated that a tree inventory was a primary component of an urban forest management programme. Many authors have confirmed this statement. Dwyer et al. (2000) and Kenney et al. (2011) assert that an inventory provides an essential basis for the understanding and management of the urban forest as it is a collection of the essential data of the trees in the forest (Sun & Bassuk, 1991; Nielsen et al. 2014). McPherson (1998) maintains that urban forestry sustainability relies on the availability of data of the urban forest structure and composition and stresses the need for a comprehensive tree inventory. The lack of a tree inventory in the CoJ, which claims to be the largest urban forest, is alarming.

The analysis highlights the incompleteness of the JCPZ tree register for this project. Even though the value of a tree inventory in a city is well known (Dwyer et al., 2000; Kenney et al., 2011), current literature suggests that there is no intention of creating such an inventory. The absence of a tree inventory in the CoJ, claiming to be the largest urban forest, is of concern. To compile an inventory, tree-specific data, inter alia tree species, age or year of planting, coordinates and description of the location, tree condition, tree dimensions and hazard status, will need to be collected (Nielsen et al., 2014). A format for an inventory was provided using literature and combining it with results from this study.

The results and analysis of data on the inventory are presented in subsequent chapters of this thesis. McPherson et al. (2018) emphasise that effective urban forestry management depends on tree inventories to aid in determining the requirements of a tree management programme, including the requirements and budgeting for tree maintenance, replacement or removal. It is also applicable for future research to determine inter alia the environmental, health and economic benefits created by this part of the urban forest.

The verification of the data on the tree register and the physical verification of these trees in their locations were used to estimate existing numbers of trees. The estimated number of existing trees for the project (in 2017-2018) is 89 644. The difference in the number of trees planted during the project (n = 206 267) and the estimated existing trees (n = 89 644) in 2017 is 116 983 trees, a survival rate of 43.46%. According to Schäffler et al. (2013), the bulk of the trees were planted during the winter, when frost conditions were prevalent, resulting in many of the trees not surviving the cold. The high mortality rate implies concerns regarding the tree planting specification, implementation and the condition and management of maintenance operations since planting.

It must be noted that the survival rate (43.46%) excludes the missing trees. When 15.37% (n = 8 151) missing trees are deducted from the estimated existing trees with addresses (n = 53

038), the estimated existing trees in 2017 may only be 44 887 trees. Missing trees include dead, absent, coppice growth only, dead stumps and stumps with coppice growth. More than half of the missing trees were recognised as presenting coppice growth, indicating a lack of maintenance and care and is not appropriate if found on an ornamental street tree in cities. *Combretum erythrophyllum* and *S. pendulina* demonstrate a tendency to form coppice growth. Keeping coppice growth under control requires constant observation and maintenance (pruning), which increases the costs of utilising these trees in an urban forest. Lewis and Boulahanis (2008) identify pruning as one of the challenges of maintenance of the urban forest and state that if the costs of maintenance could be limited, support for the management of the urban forest can be increased. The observations of the coppice growth being a concern with urban trees and with these tree species in particular could not be verified by literature. The number of absent trees reveals the inadequacy of replacing these trees, thus contributing to the negative aesthetic impression of the tree planting project. Definitive reasons for trees being missing trees were not identified.

The “absent” category of the missing trees refers to evidence of a previously planted tree in the form of an empty tree bowl and the results highlight that 28% of the missing trees were absent. The period of their absence could not be determined. As the tree register for this project is incomplete, the verification conducted in 2011 did not indicate which trees were not found and did not provide reasons for the difference in the number of trees. Therefore, a time frame for the absent trees cannot be confirmed. During the field survey a very small number of replacement trees were identified. It is the view of the researcher that the lack of replacement plants is a missed opportunity to maintain the status of the canopy cover or even improve it. By not replacing these trees, the benefits and value of these trees are forfeited. The failure to replace these trees also contributes to the aesthetical impression of the overall tree planting project.

The analysis of the JCPZ tree register and the physical verification indicate that the aim to plant trees in previously disadvantaged regions in the city was realised. In excess of 200 000 trees were planted across the CoJ and 67.99% of the trees were planted in previously disadvantaged townships across the city. It disputes the statement of the city (JCPZ, 2012) that the trees were only planted in Soweto, but confirms the aim of the project to transform the previously disadvantaged regions in the city.

The JCPZ tree register consists of limited information, for example the region, suburb, street name and number of trees. This created concerns during the verification process. The large number of trees listed as being on “various streets” and the incorrect information on the register resulted in an incomplete verification of the GSTP as not all the trees could be identified and most of them had to be excluded from this study. Therefore, the extrapolated results can only be an estimation as the locations could not be verified and therefore the existing trees could not be verified. It is of concern that such a small number of trees could be verified as existing by this study.

The field survey results identify mostly indigenous tree species planted and 13 indigenous and one exotic species across the project. Pauleit et al. (2002) refer to a few towns in northern Europe where a high percentage of planting of new street tree planting projects consists of single species or genera, but found that overall a wide range of species are used during tree planting projects. The limited tree species diversity of the project is alarming as most of the trees constitute four species only, which could increase the risk of catastrophic loss due to species-specific harmful agents. It is the opinion of the researcher that it would be an opportunity to utilise other species in large numbers and to identify which of the new species can also be used successfully in future tree planting endeavours.

Morani et al. (2011) confirm that New York City used a planting priority index to identify priority zones for tree planting for the MillionTreesNYC tree project and Los Angeles used ground-truthed data to computer-estimate potential sites for planting the Million Trees LA project trees (McPherson et al., 2011). The only published motivation for determining planting locations of the GSTP was the statement of the mayor to transform the barren wastelands and landfill sites in Soweto into winning parks, to provide eco-services and eliminate the “green divide” separating the wealthy north from the poorer south-western regions in the city.

No proof could be found to indicate community involvement in the planning of the GSTP project.

4.6 Conclusion

This study was conducted utilising the tree register provided by JCPZ. The lack of information on this register identified the need for a comprehensive tree inventory in the city. A format for such an inventory has been provided. This format can be used across South Africa as it has been customised for use in situations where technology used in developed countries such as i-Tree is not available.

The trees were not planted only in Soweto as the name of the project implies, but across the CoJ, mainly in previously disadvantaged townships. Trees were planted in streets and in parks, confirming one of the aims of the project, namely to transform the previously disadvantaged dusty regions of the city by beautifying streets and developing parks into something the city residents could be proud of.

It is estimated that of the 206 267 trees that were planted as part of the project, 89 644 trees were existing in 2017 but when the missing trees were taken into consideration there might only have been 53 038 existing in 2017. The high mortality rate of the project, exacerbated by the missing trees, is of concern as it reduces the success of the project and challenges the aim of the project to ensure that the benefits of the 2010 FIFA World Cup, in South Africa, did in fact extend beyond the event. The high mortality rate, together with the missing trees, further implies shortcomings in the management of the tree planting project, including the implementation of a tree planting specification during planting and post-planting maintenance operations, especially pruning.

The missing trees are an excellent opportunity for new tree planting to improve the value of the canopy cover, improve the species diversity, improve the number of trees in the city and prevent monocultural stands. Education of the community is necessary to prevent further vandalism and damage to trees in public spaces such as street trees and trees in public parks in the city. A dedicated effort to improve the maintenance of these trees in the city should be paramount to keeping the existing trees intact and to prevent further destruction of the urban forest. The lack of pruning identified in all the species in all the regions has been highlighted and demands attention to prevent a worst-case scenario in future. A dedicated budget is required to plan and execute formative and corrective pruning for all the tree species.

The species diversity of this study was not at an acceptable level and could have potentially adverse consequences should a pest and disease outbreak attack some of the tree species. The use of the limited species in this project provides an opportunity for future research determining a wider planting pallet of tree species suited to the urban environment and the Johannesburg climate and to determine better placement of tree species to prevent monocultural stands. The testing of tree species is imperative to ensure that the right trees are grown by suppliers in the numbers required by the city for projects such as these.

The investigation of the tree planning project emphasised the importance of successfully implementing a project of such a scale to maximise the survival of the trees. This part of the study lay the foundation for the rest of the study and identified research opportunities derived from these results. These research opportunities include the following:

- Determining the value of the contribution of the project, in its current state, to the urban forest of the CoJ
- Determining the difference in the value if all the planted trees still existed in 2018
- Determining the value of the trees planted during this project after a 30-year growth period
- Determining the growth and size of these trees

- Identifying aspects that affect the growth of these trees other than environmental conditions
- Identifying the effect of factors such as administrative region of the city, location (park, sidewalk or median of the street), land use, land cover, maintenance requirements, presence of pests and diseases, human influence surrounding the trees and conflict with the built environment on the growth of the trees
- Identifying preventative and mitigating circumstances to prevent a similar situation in future
- Determining aspects to increase the survival rate of future tree planting projects.

CHAPTER 5

GROWTH PARAMETERS OF THE TREES AND RESULTANT ALLOMETRY

5.1 Introduction

The objective of this part of the study was to determine the growth parameters of the trees and to predict the growth of these tree species by developing new allometric equations for four indigenous tree species: *Combretum erythrophyllum* (n = 543), *Olea europaea* subsp. *africana* (n = 266), *Searsia lancea* (n = 286) and *Searsia pendulina* (n = 98). Stem circumference was measured during the field survey and is presented in this chapter. The VolCalc software program was used to calculate the growth parameters using digital photographs and the results are presented together with the CGL and CBH measurements taken during the field survey. The VolCalc growth parameters are tree height (m), height of maximum canopy diameter (m), height at first leaf (m), maximum canopy diameter (m), stem diameter at first leaf (m) and volume (m^3) and are used to establish growth parameters.

To ascertain interaction between the growth parameters and the tree species, results are presented for the growth parameters for the tree species with more than 200 trees in the sample. These trees are *C. africana* (n = 358), *C. erythrophyllum* (n = 543), *S. lancea* (n = 286) and *O. europaea* subsp. *africana* (n = 266). Results are presented to identify the growth parameters and determine if trees grow differently in different regions or whether regions have an effect on growth parameters of the trees. Results are used to, among other things, detect the interaction of the species and their planting locations to establish how planting locations affect the growth parameters. The different planting locations are streets, sidewalks or medians in streets and parks. The interaction of CGL and CBH with the other growth parameters is established to determine the optimum interaction comparison and whether CGL measurements can replace CBH measurements in research on South African savannah trees.

Subsequent to the presentation of each section of the results, a discussion follows where the results are summarised, interpreted and discussed to provide clarity and relevance of the results and research questions. The findings are summarised and related to international studies and finally a conclusion highlighting the new and novel information from this study with related practical applications is provided.

5.2 Interaction of growth parameters per species for the different regions

Results to identify the interaction of the growth parameters for the four indigenous tree species in different regions in the city are presented and discussed. ANOVA was conducted to ascertain whether the means of the different regions or different species are different from each other and the F-statistics are presented per column. Comparison tables and mean values of the growth parameters are provided, each with a corresponding standard error (SE) value indicating the significance of the data within the column. The significance level (alpha) or p-value of *p ≤ 0.05, **p ≤ 0.01 and ***p ≤ 0.001 indicates the probability that the data is significant and we can be confident that the difference between the means is not by chance. Where the F-statistic value is less than 1, it is noted as "ns", or "not significant".

5.2.1 Interactions of growth parameters for *Celtis africana* trees per region

Results for the comparison of the growth parameters of *C. africana* among regions in the CoJ are presented for each growth parameter (Table 5.1). The results for tree height (m) demonstrate that the trees in Region F, with a mean height of 5.74 m, were the tallest and the trees in Region B, with a mean height of 3.46 m, were the shortest. The SE values of the tree heights of the different regions range from 0.21 to 0.31, which is less than 10% of the mean, indicating that the sample variation is low. The height of the trees in Regions C and F is not significantly different and that of the trees in Regions A and B is not significantly different, but that of the trees in Regions A, B and D is significantly different from that of the trees in Regions C and F. The F-value is 19.357***, illustrating that the difference in tree height is significant between Regions A, B, C, D and F.

The results for height of maximum canopy diameter (m) indicate that the trees in Region F, with a mean height of maximum canopy diameter of 4.21 m, had the highest canopy diameter and the trees in Region B, with a mean height of maximum canopy diameter of 2.35 m, had the lowest (Table 5.1). The SE of the height of the maximum canopy diameter of the different regions ranges from 0.08 to 0.22, which is less than 10% of the mean, revealing that the sample variation is low. The height of maximum canopy diameter of the trees in all the regions is significantly different. The F-value is 23.134***, implying that the difference in height of maximum canopy diameter is significant between Regions A, B, C, D and F.

The results for height at first leaf (m) show that the trees in Region F, with a mean height at first leaf of 2.01 m, had the highest height at first leaf and the trees in Region B, with a mean height at first leaf of 1.19 m, had the shortest height at first leaf (Table 5.1). The SE of the height at first leaf for the trees of the different regions ranges from 0.12 to 0.21. The SE for Region B is more than 10% of the mean, indicating that there are outliers, but the SE in the other regions is less than 10% of the mean, revealing that the sample variation of those regions

Table 5.1: Comparison of growth parameters of Celtis africana *between regions in CoJ*

Region	**Tree Height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Canopy volume (m^3)**	**CGL**	**CBH**
A	4.00±0.24c	2.90±0.15c	1.53±0.10bc	2.72±0.12b	0.10±0.01c	7.25±0.90cd	427.25±22.62cd	242.38±26.35c
B	3.46±0.31c	2.35±0.22d	1.19±0.16c	2.01±0.26c	0.10±0.01c	5.14±1.64d	403.25±42.37d	251.50±33.14c
C	5.83±0.29a	3.87±0.15ab	2.18±0.21a	3.11±0.18b	0.13±0.01b	14.13±1.40b	624.00±31.86b	369.67±19.99b
D	4.88±0.23b	3.44±0.15b	1.93±0.09ab	2.87±0.24b	0.12±0.01bc	10.81±1.67bc	532.50±43.98bc	305.42±29.50bc
F	5.74±0.21a	4.21±0.08a	2.01±0.12a	4.39±0.20a	0.20±0.01a	27.43±2.54a	861.92±40.55a	622.17±30.57a
F-statistics								
Region	19.357***	23.134***	13.574***	31.965***	33.524***	45.919**	27.596***	34.0562***

*Mean values (M±S.E) with different letters (a, b, c, d) in a column are significant at *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001; ns = not significant; F-statistics indicate the value* is low. The results demonstrate that the height at first leaf of the trees in Regions C and F is not significantly different and neither is that of the trees in Regions A and B. However, the height at first leaf of the trees in Regions A and B is significantly different from that of the trees in Regions C and F. The height at first leaf of the trees in Regions A, B, C and F is significantly different from that of the trees in Region D. The F-value is 13.574***, showing that the difference in height at first leaf is significant between Regions A, B, C, D and F.

The results for maximum canopy diameter (m) demonstrate that the trees in Region F, with a mean diameter of 4.39 m, had the widest diameter and the trees in Region B, with a mean diameter of 2.01 m, had the smallest diameter (Table 5.1). The SE of the maximum canopy diameter of the different regions ranges from 0.12 to 0.26. The SE for Region B is more than 10% of the mean, indicating that there are outliers, but the SE in the other regions is less than 10% of the mean, indicating that the sample variation of these regions is low. The results indicate that the maximum canopy diameter of the trees in Regions A, C and D is not significantly different, but that of the trees in Regions A, C and D is significantly different from that of the trees in Regions C and F. The F-value is 31.965***, illustrating that the difference in maximum canopy diameter is significant between Regions A, B, C, D and F.

The results for stem diameter at first leaf (m) indicate that the trees in Region F, with a mean stem diameter of 0.20 m, had the widest diameter at first leaf and the trees in Regions A and B, both with a mean stem diameter of 0.10 m, had the smallest (Table 5.1). The SE of the stem diameter at first leaf of the different regions is 0.01, which is less than 10% of the mean, showing that the sample variation is low. The results show that the stem diameter at first leaf of the trees in Regions A, B and D is not significantly different, but that of the trees in Regions A, B and D is significantly different from that of the trees in Regions C and F. The F-value is 33.524***, indicating that the difference in stem diameter at first leaf is significant between Regions A, B, C, D and F.

The results for volume (m^3) demonstrate that the trees in Region F, with a mean volume of 27.43 m^3, had the largest volume and the trees in Region B, with a mean volume of 5.14 m^3, had the smallest volume (Table 5.1). The SE of the volume of the different regions ranges from 0.90 to 2.54. The SE for Regions B and D is above 10% of the mean, revealing a high sample variation, and the SE for Regions A, C and F is less than 10% of the mean, indicating that the sample variation is low in these regions. The results show that the volume of the trees in all the regions is significantly different. The F-value is 45.919**, showing that the difference in volume is significant between Regions A, B, C, D and F.

The results for CGL (mm) indicate that the trees in Region F, with a mean CGL of 861.92 mm, had the widest CGL and the trees in Region B, with a mean CGL of 403.25 mm, had the smallest CGL (Table 5.1). The SE of the CGL of the different regions ranges from 22.62 to 43.98. The SE for Region B is more than 10% of the mean, revealing that the sample variation is high and there are outliers, but the SE in the other regions is less than 10% of the mean, signalling that the sample variation is low in those regions. The results indicate that the CGL of the trees in all the regions is significantly different. The F-value is 27.596***, showing that the difference in CGL is significant between Regions A, B, C, D and F.

The results for CBH (mm) illustrate that the trees in Region F, with a mean CBH of 622.17 mm, had the widest CBH and the trees in Region A, with a mean CBH of 242.38 mm, had the smallest CBH (Table 5.1). The SE of the CBH of the different regions ranges from 19.99 to 30.57. The SE for Regions A and B is more than 10% of the mean, showing that the sample variation is high in these regions, but the SE in the other regions is less than 10% of the mean, indicating that the sample variation is low. The results demonstrate that the CBH of the trees in Regions A and B is not significantly different, but that of trees in Regions A and B is significantly different from Regions C, D and F. The F-value is 34.0562***, showing that the difference in CBH is significant between Regions A, B, C, D and F.

5.2.2 Interactions of growth parameters for *Combretum erythrophyllum* trees per region

Results for the comparison of the growth parameters of *C. erythrophyllum* between regions in the CoJ are presented for each growth parameter individually (Table 5.2). The results for tree height (m) demonstrate that the trees in Region C, with a mean height of 4.42 m, were the tallest and the trees in Region A, with a mean height of 2.53 m, were the shortest. The SE values of the tree heights of the different regions range from 0.11 to 0.23, which is less than 10% of the mean, illustrating that the sample variation is low. The height of the trees in Regions B and F is not significantly different, but that of the trees in Regions A, C and D is significantly different from that of the trees in Regions B and F. The F-value is 18.900***, demonstrating that the difference in tree height is significant between the different regions.

The results for height of maximum canopy diameter (m) illustrate that the trees in Region C, with a mean maximum height of canopy diameter of 3.07 m, had the highest canopy diameter and the trees in Region A, with a mean maximum height of canopy diameter of 1.62 m, had the lowest (Table 5.2). The SE of the height of the maximum canopy diameter of the different regions ranges from 0.07 to 0.14 which is less than 10% of the mean, indicating that the sample variation is low. The height of the maximum canopy diameter of the trees in Regions B and F is not significantly different, but that of the trees in Regions A, C and D is significantly different from that of the trees in Regions B and F. The F-value is 27.291*** and reveals that

Table 5.2: Comparison of growth parameters of Combretum erythrophyllum *between regions in CoJ*

Region	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Canopy volume (m^3)**	**CGL**	**CBH**
A	2.53±0.11d	1.62±0.07d	0.91±0.06c	1.82±0.12c	0.07±0.01d	2.89±0.50c	227.5±18.5d	144.8±14.2c
B	3.74±0.16bc	2.53±0.12b	1.49±0.06bc	2.14±0.15bc	0.79±0.05c	6.04±1.03bc	306.4±22.3d	204.6±20.1c
C	4.42±0.23a	3.07±0.14a	1.84±0.12a	3.12±0.20a	0.15±0.01d	12.96±1.93a	626.5±39.5a	458.8±30.7a
D	3.38±0.16c	2.24±0.09c	1.34±0.06bc	2.31±0.18bc	0.30±0.06b	6.69±1.34bc	393.2±27.8c	315.2±30.1b
F	ı±0.13b	2.72±0.09b	1.88±0.09b	2.45±0.20b	0.97±0.06a	8.53±2.39ab	491.3±38.6b	385.3±35.9ab
F-statistics	37.89***	50.04***	41.16***	12.86***	77.03***	6.99***	39.08***	41.17***

*Mean values (M±S.E) with different letters (a, b, c, d) in a column are significant at *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001; ns = not significant; F-statistics indicate the value* the difference in height of maximum canopy diameter is significant between the different regions.

The results for height at first leaf (m) show that the trees in Region F, with a mean height at first leaf of 1.88 m, had the highest first leaf and the trees in Region A, with a mean height at first leaf of 0.91 m, had the lowest (Table 5.2). The SE of the height at first leaf for the trees of the different regions ranges from 0.06 to 0.12, which is less than 10% of the mean, showing that the sample variation is low. The height at first leaf of the trees in Regions A, B and D is not significantly different, but that of the trees in Regions C and F is significantly different from that of the trees in Regions A, B and D. The F-value is 23.140***, illustrating that the difference in height at first leaf is significant between the different regions.

The results for maximum canopy diameter (m) indicate that the trees in Region C, with a mean canopy diameter of 3.12 m, had the widest canopy diameter and the trees in Region A, with a mean canopy diameter of 1.82 m, had the smallest canopy diameter (Table 5.2). The SE of the maximum canopy diameter of the different regions ranges from 0.12 to 0.20, which is less than 10% of the mean, revealing that the sample variation is low. The maximum canopy diameter of the trees in Regions A, B and D is not significantly different, but that of the trees in Regions C and F is significantly different from that of the trees in Regions A, B and D. The F-value is 7.865***, showing that the difference in the maximum canopy diameter of the trees is significant between the different regions.

The results for stem diameter at first leaf (m) illustrate that the trees in Region F, with a mean stem diameter of 0.97 m, had the widest diameter at first leaf and the trees in Region A, with a mean stem diameter of 0.07 m, had the smallest (Table 5.2). The SE of the stem diameter at first leaf of the different regions ranges between 0.01 and 0.61, which is less than 10% of the mean, illustrating that the sample variation is low. The stem diameter at first leaf of the trees in Regions A and C is not significantly different, but that of the trees in Regions A and C is significantly different from that of the trees in Regions B, D and F. The F-value is 82.541***, demonstrating that the difference in stem diameter at first leaf is significant between the different regions.

The results for volume (m^3) indicate that the trees in Region C, with a mean volume of 12.96 m^3, had the largest volume and the trees in Region A, with a mean volume of 2.89 m^3, had the smallest volume (Table 5.2). The SE of the volume of the different regions ranges from 0.50 to 2.39 and as these values are more than 10% of the mean in all regions, it therefore shows that the sample variation of these regions is high and there are outliers in the data. The volume of the trees in Regions A, B and D is not significantly different, but Regions A, B and D are significantly different from Regions C and F. The F-value is 25.676***, showing that the difference in volume is significant between the different regions.

The results for CGL (mm) show that the trees in Region C, with a mean CGL of 626.5 mm, had the widest CGL and the trees in Region A, with a mean CGL of 227.5 mm, had the smallest CGL (Table 5.2). The SE of the CGL of the different regions ranges from 18.5 to 38.6, which is less than 10% of the mean, illustrating that the sample variation is low. The results imply that the CGL of the trees in Regions A and B is not significantly different, but that of the trees in Regions A and B is significantly different from that of the trees in Regions C, D and F. The F-value is 21.521***, revealing that the difference in CGL is significant between the different regions.

The results for CBH (mm) show that the trees in Region C, with a mean CBH of 458.8 mm, had the widest CBH and the trees in Region A, with a mean CBH of 144.8 mm, had the smallest CBH (Table 5.2). The SE of the CBH of the different regions ranges from 14.2 to 35.9 and is less than 10% of the mean, illustrating that the sample variation in this region is low. The CBH of the trees in Regions A and B is not significantly different and that of the trees in Regions D and F is not significantly different, but that of the trees in Regions A and B and Regions D and F is significantly different from Region C. The F-value is 5.342***, showing that the difference in CBH is significant between the different regions.

5.2.3 Interactions of growth parameters for *Searsia lancea* trees per region

Results for the comparison of the growth parameters of *S. lancea* between regions in the CoJ are presented for each growth parameter (Table 5.3). The results for tree height (m) indicate that the trees in Region C, with a mean height of 3.58 m, were the tallest and the trees in Region A, with a mean height of 3.42 m, were the shortest. The SE values of the tree heights of the different regions range from 0.13 to 0.18, which is less than 10% of the mean, demonstrating that the sample variation is low. The difference in the height of the trees in all regions is not significant. The F-value is 0.80ns, showing that there is no significant difference in the tree height between Regions A, C, D and F.

The results for height of maximum canopy diameter (m) show that the trees in Region D, with a mean maximum height of canopy diameter of 2.39 m, had the highest canopy diameter and the trees in Region A, with a mean maximum height of canopy diameter of 2.11 m, had the lowest (Table 5.3). The SE of the height of maximum canopy diameter of the different regions ranges from 0.09 to 0.12, which is less than 10% of the mean, showing that the sample variation is low. The height of maximum canopy diameter of the trees in all regions is not significantly different. The F-value is 1.56ns, revealing that there is no significant difference in the height of maximum canopy diameter between Regions A. C, D and F.

Table 5.3: Comparisons of growth parameters of Searsia lancea *between regions in CoJ*

Region	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Canopy volume (m^3)**	**CGL**	**CBH**
A	3.42±0.14a	2.11±0.10a	0.88±0.08c	3.20±0.16a	0.14±0.01b	11.58±1.44a	469.20±22.64b	387.05±25.32b
C	3.58±0.18a	2.35±0.12a	1.10±0.08b	3.38±0.18a	0.22±0.02a	11.93±1.53a	652.90±39.41a	565.98±44.69a
D	3.57±0.14a	2.39±0.09a	1.18±0.06b	2.91±0.18a	0.15±0.01b	9.21±1.43a	577.80±25.38a	441.57±18.17a
F	3.44±0.13a	2.23±0.09a	1.33±0.04a	3.36±0.17a	0.22±0.03a	11.37±1.58a	491.00±23.00b	411.34±28.72b
<u>**F-statistics**</u>								
	0.80ns	1.56ns	8.08***	1.60ns	4.63**	0.68ns	8.78***	6.67***

*Mean values (M±S.E) with different letters (a, b, c, d) in a column are significant at *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001; ns = not significant; F-statistics indicating the value*

The results for height at first leaf (m) show that the trees in Region F, with a mean height at first leaf of 1.33 m, had the highest first leaf and the trees in Region A, with a mean height at first leaf of 0.88 m, had the lowest (Table 5.3). The SE of the height at first leaf for the trees of the different regions ranges between 0.04 and 0.08, which is less than 10% of the mean, indicating that the sample variation is low. The height at first leaf of the trees in Regions C and D is not significantly different, but that of the trees in Regions C and D is significantly different from that of the trees in Regions A and F. The F-value is 8.08***, showing that the difference in height at first leaf is significant between Regions A, C, D and F.

The results for maximum canopy diameter (m) illustrate that the trees in Region C, with a mean canopy diameter of 3.38 m, had the widest canopy diameter and the trees in Region D, with a mean canopy diameter of 2.91 m, had the smallest (Table 5.3). The SE of the maximum canopy diameter of the different regions ranges from 0.16 to 0.18, which is less than 10% of the mean, showing that the sample variation is low. The maximum canopy diameter of the trees in all the regions is not significantly different. The F-value is 1.60ns, indicating that there is no significant difference in the maximum canopy diameter between Regions A, C, D and F.

The results for stem diameter at first leaf (m) reveal that the trees in Regions C and F, with a mean stem diameter of 0.22 m, had the widest stem diameter at first leaf and the trees in Region A, with a mean stem diameter of 0.14 m, had the smallest (Table 5.3). The SE of the stem diameter at first leaf of the different regions ranges between 0.01 and 0.03, which is less than 10% of the mean, showing that the sample variation is low. The stem diameter at first leaf of the trees in Regions C and F is not significantly different and neither is that of the trees in Regions A and D. However, the stem diameter at first leaf of the trees in Regions C and F is significantly different from that of the trees in Regions A and D. The F-value is 4.63**, showing that the difference in stem diameter at first leaf is moderately significant between Regions A, C, D and F.

The results for volume (m^3) indicate that the trees in Region C, with a mean volume of 11.93 m^3, had the largest volume and the trees in Region D, with a mean volume of 9.21 m^3, had the smallest (Table 5.3). The SE of the volume of the different regions ranges from 1.43 to 1.58. The SE for all the regions is more than 10% of the mean, demonstrating that the sample variation is high. The volume of the trees in all the regions is not significantly different. The F-value is 0.68ns, showing that there is no significant difference in the volume of the trees between Regions A, C, D and F.

The results for CGL (mm) illustrate that the trees in Region C, with a mean CGL of 652.90 mm, had the widest CGL and the trees in Region A, with a mean CGL of 469.20 mm, had the smallest (Table 5.3). The SE of the CGL of the different regions ranges from 22.64 to 39.41, which is less than 10% of the mean, suggesting that the sample variation is low. The results show that the CGL of the trees in Regions A and F is not significantly different and neither is that of the trees in Regions C and D. However, the F-value is 8.78***, revealing that the difference in CGL is significant between Regions A, C, D and F.

The results for CBH (mm) illustrate that the trees in Region C, with a mean CBH of 565.98 mm, had the widest CBH and the trees in Region A, with a mean CBH of 387.05 mm, had the smallest (Table 5.3). The SE of the CBH of the different regions ranges from 18.17 to 44.69, which is less than 10% of the mean, revealing that the sample variation is low. The CBH of the trees in Regions A, D and F is not significantly different but that of the trees in Regions A, D and F is slightly significantly different from Region C. The F-value is 6.67***, indicating that the difference in CBH is significant between Regions A, C, D and F.

5.2.4 Interactions of growth parameters for *Olea europaea* subsp. *africana* trees per region

Results for the comparison of the growth parameters of *O. europaea* subsp. *africana* between regions in the CoJ are presented for each growth parameter (Table 5.4). The results for tree height (m) indicate that the trees in Regions C and D, both with a mean height of 3.00 m, were the tallest and the trees in Region F, with a mean height of 2.30 m, were the shortest. The SE values of the tree heights of the different regions range from 0.1 to 0.2, which is less than 10% of the mean, revealing that the sample variation is low. The height of the trees in Regions C and D is not significantly different, but that of the trees in Regions C and D is moderately significantly different from the height of the trees in Region F. The F-value is 8.050**, illustrating that the difference in tree height is moderately significant between Regions C, D and F.

The results for height of maximum canopy diameter (m) show that the trees in Region D, with a mean maximum height of canopy diameter of 2.01 m, had the highest canopy diameter and the trees in Region F, with a mean maximum height of canopy diameter of 1.67 m, had the lowest (Table 5.4). The SE of the height of maximum canopy diameter of the different regions is 0.1, which is less than 10% of the mean, illustrating that the sample variation is low. The height of maximum canopy diameter of the trees in all regions is not significantly different. The F-value is 2.544ns, indicating that the difference in height of maximum canopy diameter is not significant between Regions C, D and F.

The results for height at first leaf (m) show that the trees in Region D, with a mean height at first leaf of 1.23 m, had the highest first leaf and the trees in Region F, with a mean height at first leaf of 1.10 m, had the lowest (Table 5.4). The SE of the height at first leaf for the trees of the different regions is 0.1, which is less than 10% of the mean, demonstrating that the sample

Table 5.4: Comparisons of growth parameters of Olea europaea subsp. africana *between regions in CoJ*

Region	Tree height (m)	Height max canopy diameter (m)	Height at first leaf (m)	Max canopy diameter (m)	Stem diameter at first leaf (m)	Canopy volume (m^3)	CGL	CBH
C	3.00±0.2a	1.89±0.1a	1.19±0.1a	2.32±0.2a	0.14±0.03a	5.29±0.5a	332.22±40.4b	248.72±34.8b
D	3.00±0.1a	2.01±0.1a	1.23±0.1a	2.54±0.2a	0.14±0.02a	5.71±0.4a	478.72±31.0a	328.28±26.2a
F	2.30±0.1b	1.67±0.1a	1.10±0.1a	1.54±0.1b	0.09±0.01a	1.43±0.2b	266.94±15.3c	192.73±14.5c
F-statistics								
Region	8.050**	2.544ns	0.849ns	10.755***	2.390ns	6.764**	16.882***	9.061***

*Mean values (M±S.E) with different letters (a, b, c, d) in a column are significant at *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001 and ns = not significant and F-Statistics indicating the value* variation is low. The height at first leaf of the trees in all regions is not significantly different. The F-value is 0.849ns, showing that the difference in height at first leaf is not significant between Regions C, D and F.

The results for maximum canopy diameter (m) indicate that the trees in Region D, with a mean canopy diameter of 2.54 m, had the widest canopy diameter and the trees in Region F, with a mean canopy diameter of 1.54 m, had the smallest (Table 5.4). The SE of the maximum canopy diameter of the different regions ranges from 0.1 to 0.2, which is less than 10% of the mean, showing that the sample variation is low. The maximum canopy diameter of the trees in Regions C and D is not significantly different, but that of the trees in Regions C and D is significantly different from the maximum canopy diameter of the trees in Region F. The F-value is 10.755***, indicating that the difference in the maximum canopy diameter of the trees is significant between the Regions C, D and F.

The results for stem diameter at first leaf (m) show that the trees in Regions C and D, both with a mean stem diameter of 0.14 m, had the widest stem diameter at first leaf and the trees in Region F, with a mean stem diameter at first leaf of 0.09 m, had the smallest (Table 5.4). The SE of the stem diameter at first leaf of the different regions ranges between 0.03 and 0.01, which is less than 10% of the mean, showing that the sample variation is low. The stem diameter at first leaf of the trees for all the regions is not significantly different. The F-value is 2.390ns, showing that the difference in stem diameter at first leaf is not significant between Regions C, D and F.

The results for volume (m^3) indicate that the trees in Region D, with a mean volume of 5.71 m^3, had the largest volume and the trees in Region F, with a mean volume of 1.43 m^3, had the smallest (Table 5.4). The SE of the volume of the different regions ranges from 0.5 to 0.2. The SE for Region F is more than 10% of the mean, revealing that the sample variation is high and there are outliers. However, the SE in the other regions is less than 10% of the mean, illustrating that the sample variation is low. The volume of the trees in Regions C and D is not significantly different, but that of the trees in Regions C and D is significantly different from the volume of the trees in Region F. The F-value is 6.764**, showing that the difference in volume is moderately significant between Regions C, D and F.

The results for CGL (mm) demonstrate that the trees in Region D, with a mean CGL of 478.72 mm, had the widest CGL and the trees in Region F, with a mean CGL of 266.94 mm, had the smallest (Table 5.4). The SE of the CGL of the different regions ranges from 15.3 to 40.4. The SE for Region A is more than 10% of the mean, indicating that there are outliers. However, the SE in the other regions is less than 10% of the mean, demonstrating that the sample variation is low. The CGL of the trees of all the regions is significantly different. The F-value is 16.882***, showing that the difference in CGL is significant between Regions C, D and F.

The results for CBH (mm) reveal that the trees in Region D, with a mean CBH of 328.28 mm, had the widest CBH and the trees in Region F, with a mean CBH of 192.73 mm, had the smallest (Table 5.4). The SE of the CBH of the different regions ranges from 14.5 to 34.8. The SE for Region A is more than 10% of the mean, showing that the sample variation is high and there are outliers, but the SE in the other regions is less than 10% of the mean, showing that the sample variation is low. The CBH of the trees in all the regions is significantly different. The F-value is 9.061***, illustrating that the difference in CBH is significant between Regions C, D and F.

5.2.5 Discussion: Interaction of the growth parameter results

The results are based on mean measurements for all the growth parameters of the individual trees. Coates Palgrave (1983) states that the height of mature *C. africana* trees should be between 12 m and 30 m, that of mature *C. erythrophyllum* should be 12 m, that of mature *S. lancea* trees should be about 8 m and that of mature *O. europaea subsp. africana* should be between 5 m and 10 m.. In this study the mean height of the tallest *C. africana* trees was 5.74 m, the mean height of the tallest *C. erythrophyllum* was 4.42 m, that of the tallest *S. lancea* was 3.58 m and that of the tallest *O. europaea subsp. africana* was 3.00 m. It is evident from the results that the trees in the study were smaller than the mature sizes and therefore still young.

The interaction of the growth parameters in the different regions indicates that the *C. africana* trees in Region F were larger, as all of the mean measurements of the growth parameters were significantly different and larger than in the other regions. The growth parameters of *C. africana* trees in Region B were on average significantly smaller than the trees in the other regions, except for CBH where the smallest mean trees were found in Region A. These trees were all found in one park (Donga Street Park) and were planted in 2007. Even though these trees were planted after the largest trees, there were *C. africana* trees in Regions A and D that were planted between 2006 and 2009 that were younger but larger than the trees in Region B. The reason for the small trees in Region B may be unfavourable environmental conditions or other site features and external factors negatively affecting the growth of the trees. A concern to be highlighted is the trees planted in 2006 in Region D, which were smaller on mean than the trees planted in any of the other years. The possible incorrectness of the information provided by JCPZ on the tree register could be a reason for the variation in the data. A map of the different regions (A, B, C, D, and F) is included as Figure 5.1 to identify the location of the regions.

The interaction of the growth parameters in the different regions indicates that the *C. erythrophyllum* trees in Region C were larger, as most of the mean measurements of the growth parameters were significantly different and larger than in the other regions. The height at first leaf and stem diameter at first leaf of the trees in Region F were significantly different and higher and wider, respectively, than those of the trees in the other regions. The trees in this region were found mostly on sidewalks of streets in formal residential areas and in parks and were planted between 2006 and 2008, providing a possible reason for the larger trees. The growth parameters of *C. erythrophyllum* trees in Region A were on mean significantly smaller than those of the trees in the other regions. These trees were all found in one street in the Rivonia area, on the sidewalk, and were planted in 2010. The reason for the small trees in Region A may be that they were planted after the trees in Region C, therefore being the youngest, but it could also be due to environmental conditions not being as favourable in Region C, as the smaller trees were all found in one area in this region.

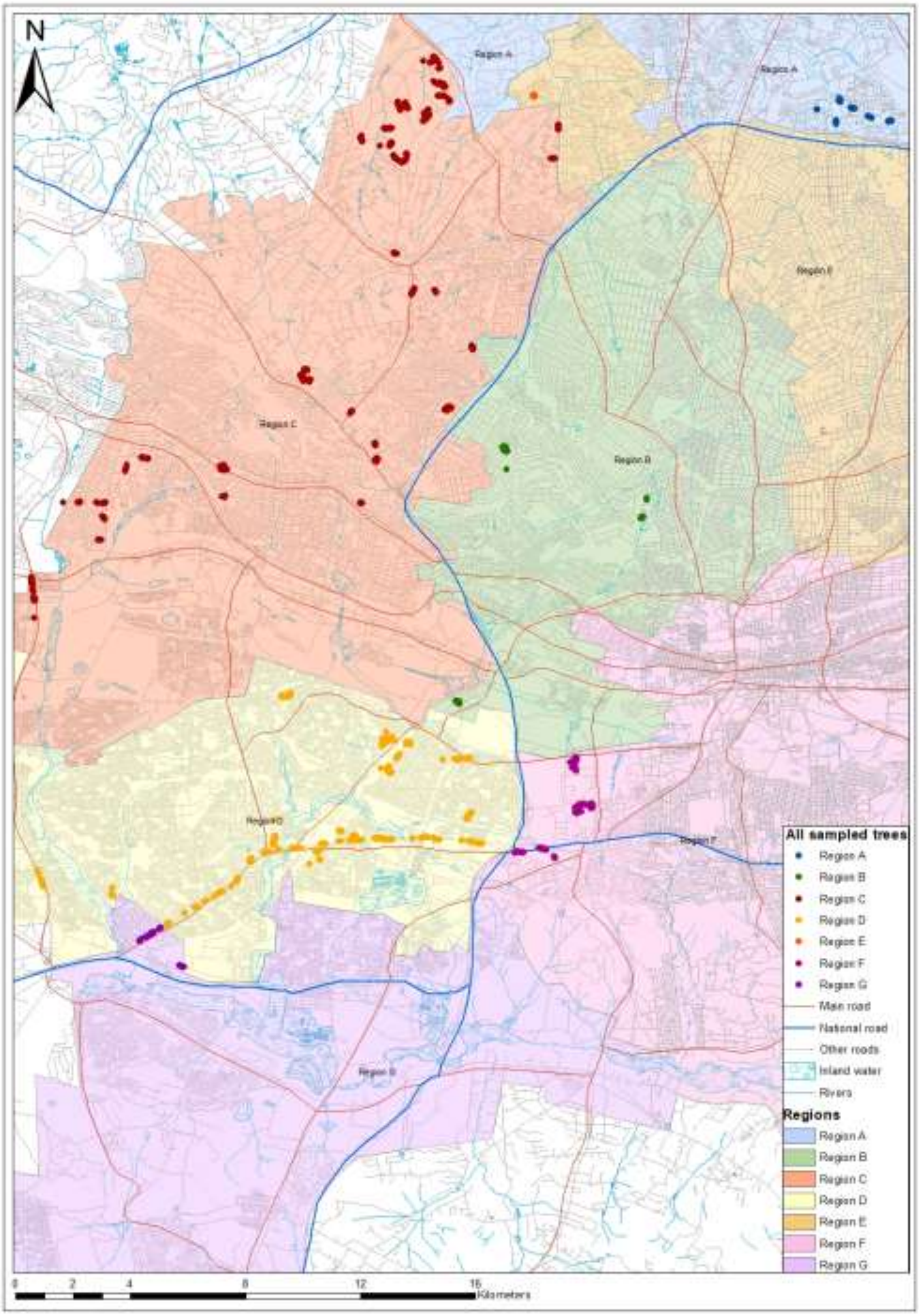


Figure 5.1: Different regions in CoJ, with the trees plotted in the same colour per region

The interaction of the growth parameters in the different regions indicates that most of the *S. lancea* trees in Region C were larger, as most of the mean measurements of the growth parameters were significantly different and larger than in the other regions. The only difference is the height of maximum canopy diameter where the largest mean trees were found in Region D. The trees in Region C were mostly street trees on sidewalks with some planted in parks, planted mostly between 2006 and 2008. This is a possible reason for the larger trees, as they are older than the other trees. The trees planted in 2009 were smaller on average than the trees planted in the previous years. The growth parameters of *S. lancea* trees in Region A were on average significantly smaller than those of the trees in the other regions, except for the maximum canopy diameter and volume where the smallest trees were found in Region D. These trees in Region D were planted in 2006 in a park and should not have been as small as they were older than the other trees. The smaller trees in Region A were mostly street trees on sidewalks in the Rivonia area and planted in 2010, which correlates with their smaller size. There were also a small number of *S. lancea* trees found in a park (Bloubosrand Park) and were planted in 2007 in this region. The small size of these trees may be attributed to them being younger than the trees in Region C. The results of the growth parameter interaction of height, height of maximum canopy diameter, maximum canopy diameter and volume were not significant.

The interaction of the growth parameters in the different regions indicates that the O*. europaea subsp. africana* trees in Region D were larger, as all of the mean measurements of the growth parameters were mostly significantly different and larger than in the other regions. The height and stem diameter at first leaf for the trees in Region D were also higher and wider, respectively, than in the other regions. The trees in this region were found on sidewalks and medians of streets in formal residential areas and in parks. The trees were planted between 2005 and 2010, providing a possible reason why some of the trees were larger (see section 5.3). The growth parameters of *O. europaea subsp. africana* trees in Region F were on average significantly smaller than those of the trees in the other regions. These trees were all found in one street in the Soccer City precinct, planted on a steep sloped sidewalk in 2005. The reason for the trees being significantly smaller in this region may be unfavourable soil conditions or other site features and external factors negatively affecting the growth of the trees, or incorrect planting dates found on the JCPZ tree register. Many of the trees were planted in a park that was previously a waste disposal site. This may have influenced the growth conditions of the trees. The results of the growth parameter interaction of height of maximum canopy diameter, height at first leaf and stem diameter at first leaf were not significant.

In summary, the trees with the largest growth parameters were found mostly in Regions C, D and F. None of the largest growth parameters were found in Regions A and B. The trees with the smallest growth parameters were found mostly in Regions A, B, D and F. None of the smallest growth parameters were found in Region C. Therefore, it can be deduced that the trees in Region C were growing better than those in the other regions. Even though the different regions in the city are in close proximity to each other and the environmental conditions should be similar in all the regions, it can be assumed that the micro-climatic environmental conditions and soil properties are different and that may contribute to the differences in tree size. The differences in the micro-climate of specific study sites may also influence the growth of the trees.

5.3 Comparisons of parameters per species in different growth environments

Results regarding comparisons of the growth parameters for the four species between sidewalks and medians in streets and between streets and parks in regions in the city are presented and discussed. The aim was to establish if trees grow better on sidewalks, in medians or in parks. Results are only presented where the different tree species were found in both parameters (sidewalks and medians) in a region. Where trees were found in only one parameter, for example only on sidewalks and not on medians in a region, results are not presented. ANOVA was conducted to establish whether the means of the groups (different regions or different species) are different from each other and the F-statistics are presented per column. The results are in the form of comparison tables and mean values of the growth parameters are presented, each with a corresponding SE value and letters to indicate the significance of the data within the column. The significance level (alpha) or p-value of $^{*}p \leq 0.05$, $^{**}p \leq 0.01$ and $^{***}p \leq 0.001$ indicate the probability that the evidence is significant that the difference between the means provided is not by chance. Where the F-statistic value is less than 1, it is noted as “ns” and indicates that the evidence is not significant.

5.3.1 Analysis of growth parameters of *Celtis africana* trees on medians and sidewalks in streets in Region C

Results for the comparison of the growth parameters of *C. africana* are presented for each growth parameter as seen in Table 5.5.

The results for tree height (m) indicate that the trees planted on the sidewalks in Region C, with a mean height of 3.71 m, were taller than the trees on medians, with a mean height of 2.85 m. The SE values of the tree heights range from 0.13 to 0.20, which is less than 10% of the mean, indicating that the sample variation is low. As seen in Table 5.5, the height of the trees planted on sidewalks is significantly different from that of the trees planted on medians.

The results for height of maximum canopy diameter (m) illustrate that the trees planted on the sidewalk in Region C, with a mean height of maximum canopy diameter of 2.46 m, had a higher canopy diameter than the trees in planted on the median, with a mean height of maximum canopy diameter of 2.08 m (Table 5.5). The SE of the height of maximum canopy diameter ranges from 0.09 to 0.14, which is less than 10% of the mean, indicating that the

Table 5.5: Comparison of growth parameters of Celtis africana *between medians and sidewalks in streets in Region C*

Region	**Land use**	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Canopy volume (m^3)**	**CGL**	**CBH**
C	Median	2.85±0.13b	2.08±0.09b	1.08±0.10a	1.87±0.13b	0.05±0.01b	2.47±0.40b	281±26.56b	152±12.06b
C	Sidewalk	3.71±0.20a	2.46±0.14a	1.19±0.10a	3.17±0.14a	0.14±0.02a	10.73±1.39a	703±47.51a	461±41.96a

Mean values (M±S.E) with different letters (a, b) in a column are significant at p ≤ 0.05.

sample variation is low. The height of maximum canopy diameter of the trees planted on the sidewalks is significantly different from that of the trees planted on medians.

The results for height at first leaf (m) indicate that the trees planted on the sidewalk in Region C, with a mean maximum height at first leaf of 1.19 m, had the higher first leaf than the trees in planted on the median, with a mean maximum height at first leaf of 1.08 m (Table 5.5). The SE of the height at first leaf of the trees planted on the sidewalk and on the median is the same at 0.10 and less than 10% of the mean, showing that the sample variation is low. The height at first leaf of the trees planted on the sidewalks and that of the trees planted on the medians in Region C is not significantly different.

The results for maximum canopy diameter (m) illustrate that the trees planted on the sidewalk in Region C, with a mean maximum canopy diameter of 3.17 m, had a wider diameter than that of the trees planted on the median, with a mean maximum canopy diameter of 1.87 m (Table 5.5). The SE of the maximum canopy diameter ranges from 0.13 to 0.14, which is less than 10% of the mean, indicating that the sample variation is low. The results reveal that the maximum canopy diameter of the trees planted on sidewalks and of the trees planted on medians is significantly different in Region C. The difference in maximum canopy diameter is significant between the sidewalks and the medians.

The results for stem diameter at first leaf (m) indicate that the trees planted on the sidewalk in Region C, with a mean stem diameter of 0.14 m, had the widest stem diameter at first leaf and the trees planted on the median, with a mean stem diameter of 0.05 m, had the smallest (Table 5.5). The SE of the stem diameter at first leaf for the trees planted on the median is 0.01, which is less than 10% of the mean, demonstrating that the sample variation is low. The SE of the stem diameter at first leaf for the trees planted on the sidewalks is 0.02, which is more than 10% of the mean, showing a high variation in the sample. The stem diameter at first leaf of the trees planted on the sidewalks is significantly different from that of the trees planted on the medians in Region C.

The results for volume (m^3) indicate that the trees planted on the sidewalk in Region C, with a mean volume of 10.73 m^3, had the largest volume and the trees planted on the median, with a mean volume of 2.47 m^3, had the smallest (Table 5.5). The SE of the volume of the trees planted in the different locations ranges from 0.40 to 1.39. The SE for both the sidewalk and median trees is above 10% of the mean, which implies a high sample variation with outliers. The volume of the trees on the sidewalks is significantly different from that of the trees on the medians.

The results for CGL (mm) indicate that the trees planted on the sidewalk in Region C, with a mean CGL of 703 mm, had the widest CGL and the trees planted on the median, with a mean

CGL of 281 mm, had the smallest (Table 5.5). The SE of the CGL of the trees planted on the sidewalks and medians ranges from 47 mm to 26 mm. The SE for both the sidewalk and median trees is less than 10% of the mean, illustrating that the sample variation is low. The CGL of the trees planted on the sidewalks is significantly different from that of the trees planted on the medians.

The results for CBH (mm) are that the trees planted on the sidewalk in Region C, with a mean CBH of 461 mm, had the widest CBH and the trees planted on the medians, with a mean CBH of 152 mm, had the smallest (Table 5.5). The SE of the CBH of the trees planted on the sidewalks and the medians ranges from 12 mm to 41 mm. The SE for both the sidewalk and the median trees is less than 10% of the mean, indicating that the sample variation is low. The CBH of the trees planted on the sidewalks and that of the trees planted on the medians in Regions C is significantly different.

5.3.2 Analysis of growth parameters of *Celtis africana* trees on streets and parks in Regions C and D

The results for *C. africana* in the streets are a combination of the trees planted on sidewalks and those planted on the medians and are a comparison of the individual growth parameters (Table 5.6).

The results for tree height (m), as seen in Table 5.6, indicate that the trees planted in the parks in Region C, with a mean height of 4.63 m, and in Region D, with a mean height of 5.34 m, were taller than the trees planted in the streets in Region C, with a mean height of 4.23 m, and in Region D, with a mean height of 3.65 m. In other words, the trees in the parks in both regions were taller than the trees in the streets in these regions. The SE values of the tree heights range from 0.13 to 0.16, which is less than 10% of the mean, revealing that the sample variation is low. The height of the trees planted in streets is significantly different from that of the trees planted in parks between the regions and between the streets and parks in the regions.

The results for height of maximum canopy diameter (m) show that the trees planted in parks in Region C, with a mean height of maximum canopy diameter of 3.72 m, and in Region D, with a mean height of maximum canopy diameter of 3.26 m, had a higher maximum canopy diameter than the trees in planted in the streets of Regions C (2.99 m) and D (2.62 m) (Table 5.6). In other words, the trees in both the streets and parks in Region C had a higher maximum canopy diameter than the trees in the street and parks in Region D. In both regions the trees in parks had a higher maximum canopy diameter than the trees in the street. The SE of the height of maximum canopy diameter ranges from 0.79 to 0.11, which is less than 10% of the

Table 5.6: Comparison of Celtis africana *trees growing in parks and streets in Regions C and D*

Region	**Land use**	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Canopy volume (m^3)**	**CGL**	**CBH**
C	Park	5.34±0.16aA	3.72±0.11aA	2.15±0.01aA	3.03±0.12aA	0.16±0.0aA	12.70±1.20aA	640±28.03aA	396±17.46aA
	Street	4.23±0.16bB	2.99±0.11bB	1.85±0.07aA	3.17±0.09aA	0.11±0.0bA	10.28±0.85bB	459±23.36bB	291±14.57bB
D	Park	4.63±0.13aAB	3.26±0.08aAB	1.95±0.06aA	2.86±0.1aA	0.11±0.0aA	9.66±0.85aB	556±22.96aA	354±22.47aA
	Street	3.65±0.14bC	2.62±0.07bB	1.56±0.04aA	2.76±0.1aA	0.09±0.0bB	6.82±0.62bC	386±22.11bB	252±17.66bB

Values (M ± S.E.) followed by dissimilar letters (in upper case A, B, C) within a column for both regions are significantly different at $p \leq 0.05$. Values (M ± S.E.) followed by dissimilar letters (in lower case a, b) within a column for each region are significantly different at $p < 0.05$.

mean, showing that the sample variation is low. The height of maximum canopy diameter of the trees planted in the streets is significantly different from that of the trees in parks.

The results (Table 5.6) for height at first leaf (m) indicate that the trees planted in the parks in Region C, with a mean height at first leaf of 2.15 m, and in Region D, with a mean height of first leaf of 1.95 m, had a higher first leaf than the trees planted in the streets in Regions C (1.85 m) and D 1.56 m). In other words, the trees in both the streets and parks in Region C had a higher first leaf than the trees in the street and parks in Region D. The SE of the height at first leaf for the trees of the different regions ranges from 0.01 to 0.07, which is less than 10% of the mean, showing that the sample variation is low. The height at first leaf of the street trees and the park trees planted in both regions is not significantly different.

The results (Table 5.6) for maximum canopy diameter (m) indicate that the trees planted in the streets in Region C, with a mean maximum canopy diameter of 3.17 m, had a wider mean maximum canopy diameter than those planted in the parks in Region C, with a mean canopy diameter of 3.03 m. The park trees in Region D, with a mean maximum canopy diameter of 2.86 m, had a wider maximum canopy diameter than the street trees in Region D, with a mean maximum canopy diameter of 2.76 m. The mean measurements of the trees in Region C are therefore wider than those of the trees in Region D. The SE of the maximum canopy diameter ranges from 0.01 to 0.12, which is less than 10% of the mean, illustrating that the sample variation is low. The maximum canopy diameter of the street trees and the park trees is not significantly different in either the regions or in the streets and parks.

The results for stem diameter at first leaf (m) indicate that the trees planted in the parks in Region C, with a mean stem diameter at first leaf of 0.16 m, and the trees planted in the parks in Region D, with a mean stem diameter at first leaf of 0.11 m, had the widest stem diameter at first leaf. The trees planted in the streets of Region C, with a mean stem diameter of 0.11 m, and the trees planted in the streets of Region D, with a mean stem diameter of 0.09 m, had the smallest stem diameter at first leaf (Table 5.6). In other words, both the street trees and park trees in Region C had a wider stem diameter at first leaf than the street trees and park trees in Region D. The SE of the stem diameter at first leaf for both the street and park trees in both regions is 0.00, which is less than 10% of the mean, indicating that the sample variation is low. The stem diameter at first leaf of the street trees in Region D is significantly different, but the stem diameter at first leaf of the trees planted in the streets and in parks in Region C is not significantly different. The stem diameter at first leaf of the park trees in Regions C and D is not significantly different.

The results (Table 5.6) for volume (m^3) indicate that the park trees in Region C, with a mean volume of 12.70 m^3, and the park trees in Region D, with a mean volume of 9.66 m^3, had the largest volume. The street trees in Region C, with a mean volume of 10.28 m^3, and the street trees in Region D, with a mean volume of 6.82 m^3, had the smallest volume. In other words, the park trees in Region C had a larger volume than the street trees in Region C, and the park trees in Region D had a larger volume than the street trees in Region D. The mean measurements of the trees in Region C are therefore larger than those of the trees in Region D. The SE of the volume of the different regions ranges from 0.85 to 1.20. The SE for both the street and park trees is less than 10% of the mean, revealing that the sample variation is low. The volume of the trees in both the regions is significantly different.

The results for CGL (mm) indicate that the park trees in Region C, with a mean CGL of 640 mm, and the street trees in Region C, with a mean CGL of 459 mm, had the widest CGL. The park trees in Region D, with a mean CGL of 556 mm, and the street trees in Region D, with a mean CGL of 386 mm, had the smallest CGL (Table 5.6). In other words, the trees planted in parks in Region C had a wider CGL than those planted in streets in Region C, and the trees planted in parks in Region D had a wider CGL than those planted in streets in Region D. The mean measurements of the trees in Region C are therefore wider than those of the trees in Region D. The SE of the CGL of the trees planted in the streets and parks ranges from 22 mm to 28 mm. The SE for both the street and park trees is less than 10% of the mean, indicating that the sample variation is low. The CGL of the trees planted in the streets and parks is significantly different between the regions, but not significant between the street and park trees in both regions.

The results for CBH (mm) show that the trees planted in the parks in Region C, with a mean CBH of 396 mm, and the trees planted in the streets in Region C, with a mean CBH of 291 mm, had the widest CBH. The trees planted in the parks in Region D, with a mean CBH of 354 mm, and the trees planted in the streets in Region D, with a mean CBH of 252 mm, had the smallest CBH (Table 5.6). In other words, the trees planted in parks in Region C had a wider CBH than those planted in streets in Region C, and the trees planted in parks in Region D had a wider CBH than those planted in streets in Region D. The mean measurements of the trees in Region C are therefore wider than those of the trees in Region D. The SE of the CBH of the trees planted in the streets and parks ranges from 14 mm to 22 mm. The SE for both the street and park trees is less than 10% of the mean, demonstrating that the sample variation is low. The CBH of the trees planted in the streets and parks is significantly different between the regions, but not significant between the street trees and the park trees in both regions.

5.3.3 Analysis of growth parameters of *Combretum erythrophyllum* trees on medians and sidewalks in streets in Region D

Results for the comparison of each of the individual growth parameters of *C. erythrophyllum* are presented below and can be seen in Table 5.7.

The results for tree height (m) indicate that the trees planted on the medians in Region D, with a mean height of 4.27 m, were taller and the trees on sidewalks, with a mean height of 3.85 m, were shorter (Table 5.7). The SE values of the tree heights range from 0.14 to 0.19, which is less than 10% of the mean, indicating that the sample variation is low. The height of the trees planted on sidewalks is not significantly different from that of the trees planted on medians.

The results for height of maximum canopy diameter (m) indicate that the trees planted on the median in Region D, with a mean height of maximum canopy diameter of 2.88 m, had a higher maximum canopy diameter than the trees planted on the sidewalk (2.57 m), seen in Table 5.7. The SE of the height of maximum canopy diameter ranges from 0.11 to 0.14, which is less than 10% of the mean, revealing that the sample variation is low. The height of maximum canopy diameter of the sidewalk trees is not significantly different from that of the median trees.

The results for height at first leaf (m) in Table 5.7 reveal that the trees planted on the median in Region D, with a mean maximum height at first leaf (2.03 m), had a higher first leaf than the trees planted on the sidewalk, with a mean height at first leaf of 1.67 m. The SE of the height at first leaf for the trees of the different regions is the same at 0.09 and is less than 10% of the mean, indicating that the sample variation is low. The height at first leaf of the trees planted on the sidewalk is not significantly different from that of the trees planted on the medians in Region D.

The results for maximum canopy diameter (m) indicate that the trees planted on the sidewalks in Region D, with a mean maximum canopy diameter of 2.78 m, had a wider mean diameter than those planted on the medians, with a mean diameter of 2.62 m (Table 5.7). The SE of the maximum canopy diameter ranges from 0.13 to 0.23, which is less than 10% of the mean, demonstrating that the sample variation is low. The maximum canopy diameter of the trees planted on sidewalks is not significantly different from that of the trees planted on medians.

The results for stem diameter at first leaf (m) in Table 5.7 indicate that the trees planted on the sidewalk in Region D, with a mean stem diameter at first leaf of 0.35 m, had the widest stem diameter at first leaf. The trees planted on the median, with a mean stem diameter at first leaf of 0.29 m, had the smallest stem diameter at first leaf. The SE of the stem diameter

Table 5.7: Comparison of growth parameters of Combretum erythrophyllum *between medians and sidewalks in streets in Region D*

Land use	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Canopy volume (m^3)**	**CGL**	**CBH**
Sidewalk	3.85±0.19a	2.57±0.14a	1.67±0.09b	2.78±0.23a	0.35±0.10a	10.44±2.45a	457.75±24.41a	330.91±23.57a
Median	4.27±0.14a	2.88±0.11a	2.03±0.09b	2.62±0.13a	0.29±0.04a	7.91±0.98a	376.50±14.27b	258.00±10.90b

Mean values (M±S.E) with different letters (a, b) in a column are significant at p ≤ 0.05.

at first leaf for the trees planted on the median ranges between 0.04 and 0.10, which is less than 10% of the mean, indicating that the sample variation is low. The stem diameter at first leaf of the trees planted on the sidewalks is not significantly different from that of the trees planted on the medians in Region D.

The results for volume (m^3), as seen in Table 5.7, show that the trees planted on the sidewalk in Region D, with a mean volume of 10.44 m^3, had the largest volume and the trees planted on the medians, with a mean volume of 7.91 m^3, had the smallest volume. The SE of the volume of the trees planted on the sidewalks and medians ranges from 0.98 to 2.45. The SE for both the sidewalks and medians is above 10% of the mean, indicating a high sample variation with outliers. The volume of the sidewalk trees is not significantly different from that of the median trees.

The results for CGL (mm) indicate that the trees planted on the sidewalk in Region D, with a mean CGL of 457.75 mm, had the widest CGL and the trees planted on the median, with a mean CGL of 376.50 mm, had the smallest (Table 5.7). The SE of the CGL of the trees planted on the sidewalks and medians ranges from 14.41 to 46.41. The SE for both the sidewalk and median trees is less than 10% of the mean, revealing that the sample variation is low. The CGL of the trees planted on the sidewalks is significantly different from that of the trees planted on the medians.

The results for CBH (mm) demonstrate that the trees planted on the sidewalk in Region D, with a mean CBH of 330.91 mm, had the widest CBH and the trees planted on the medians, with a mean CBH of 258.00 mm, had the smallest (Table 5.7). The SE of the CBH of the trees planted on the sidewalks and medians ranges from 10.90 to 23.57. The SE for both the sidewalk and the median trees is less than 10% of the mean, indicating that the sample variation is low. The CBH of the trees planted on the sidewalks and is significantly different from the trees planted on the medians.

5.3.4 Analysis of growth parameters of *Combretum erythrophyllum* trees in streets and parks in Regions C and D

The results for the streets include the trees planted on sidewalks and medians and the growth parameters of *C. erythrophyllum* are compared between streets and parks in both regions (Table 5.8). Each of the growth parameters is presented separately but seen together in Table 5.8.

The results for tree height (m) indicate that the trees planted in the streets in Region D, with a mean height of 4.06 m, were taller than the trees planted in the streets in Region C, with a mean height of 2.84 m. The park trees in Region C, with a mean height of 3.83 m, were taller than the park trees in Region D, with a mean height of 3.33 m. In other words, the street trees were taller than the park trees in Region D, but the park trees were taller than the street trees in Region C. The SE values of the tree heights range from 0.12 to 0.20, which is less than 10% of the mean, indicating that the sample variation is low. The height of the street trees is significantly different, but that of the park trees in Regions C and D is not significantly different.

The results for height of maximum canopy diameter (m), as seen in Table 5.8, illustrate that the trees planted in parks in Region C, with a mean height of maximum canopy diameter of 2.50 m, had a higher maximum canopy diameter than the park trees in Region D, with a mean height of maximum canopy diameter of 2.25 m. The street trees in Region D, with a mean height of maximum canopy diameter of 2.73 m, had a higher maximum canopy diameter than the trees planted in the streets of Region C, with a mean height of maximum canopy diameter of 1.94 m. The SE of the height of maximum canopy diameter ranges from 0.08 to 0.11, which is less than 10% of the mean, showing that the sample variation is low. The height of maximum canopy diameter of the trees planted in the streets is significantly different from that of the trees planted in parks.

The results for height at first leaf (m) show that the trees planted in the parks in Region C, with a mean height at first leaf of 1.44 m, had a higher first leaf than the trees planted in parks in Region D, with a mean height at first leaf of 1.36 m. The trees in planted in the streets of Region D, with a mean height at first leaf of 1.85 m, had a higher first leaf than the trees planted in the streets of Region C, with a mean height at first leaf of 1.11 m. The SE of the height at first leaf for the trees of the different regions ranges from 0.05 to 0.07 and is less than 10% of the mean, indicating that the sample variation is low. The height at first leaf of the street trees and the park trees in both regions is significantly different.

The results for maximum canopy diameter (m) indicate that the trees planted in the parks in Region C, with a mean maximum canopy diameter of 2.61 m, had a wider mean canopy diameter than the trees planted in the parks in Region D, with a mean canopy diameter of 2.27 m (Table 5.8). The street trees in Region D, with a mean maximum canopy diameter of 2.70 m, had a wider mean canopy diameter than the street trees in Region C, with a mean maximum canopy diameter of 1.82 m. The SE of the maximum canopy diameter ranges from 0.13 to 0.21, which is less than 10% of the mean, showing that the sample variation is low. The maximum canopy diameter of the street and park trees is not significantly different in Region D. It is also not significantly different from that of the park trees in Region C, but it is significantly different from that of the street trees in Region C.

The results for stem diameter at first leaf (m), seen in Table 5.8, indicate that the trees planted in the parks in Region C, with a mean stem diameter at first leaf of 0.32 m, were wider than

Table 5.8: Comparison of Combretum erythrophyllum *trees growing in parks and streets in Regions C and D*

Region	**Land use**	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Canopy volume (m^3)**	**CGL**	**CBH**
C	Park	3.83±0.20aB	2.50±0.11aA	1.44±0.06aAB	2.61±0.21aA	0.93±0.10aA	13.56±3.43aA	535.01±38.34a	373.45±28.71aA
	Street	2.84±0.15bC	1.94±0.08bB	1.11±0.06bB	1.82±0.15bB	0.07±0.01bB	3.79±0.82bC	289.81±14.31b	194.74±13.71bC
D	Park	3.33±0.13bB	2.25±0.08bAB	1.36±0.05bB	2.27±0.14aA	0.53±0.08bB	6.14±1.04aB	439.58±25.25a	350.44±24.29aAB
	Street	4.06±0.12aA	2.73±0.09aA	1.85±0.07aA	2.70±0.13aA	1.03±0.06aA	9.18±1.32aB	417.13±15.40a	294.46±14.08aB

Values (M ± S.E.) followed by dissimilar letters (in upper case A, B, C) within a column for both regions are significantly different at $p \leq 0.05$. Values (M ± S.E.) followed by dissimilar letters (in lower case a, b) within a column for each region are significantly different at $p < 0.05$.

the trees planted in the parks in Region D, with a mean stem diameter at first leaf of 0.28 m. The street trees with the widest mean stem diameter at first leaf were in Region D, with a mean stem diameter of 0.38 m, compared to the street trees in Region C, with a mean stem diameter of 0.07 m. The SE of the stem diameter at first leaf ranges from 0.01 to 0.10, which is less than 10% of the mean for street trees in Regions C and D, showing that the sample variation is low. The SE is higher than 10% for the park trees in both regions, indicating high variation with outliers. The stem diameter at first leaf of the trees planted in Region C is significantly different from that of the trees planted in Region D. However, the stem diameter at first leaf of the street trees in Region D is not significantly different from that of the park trees in Region C, and stem diameter at first leaf of the street trees in Region C is not significantly different from that of the street trees in Region D.

The results for volume (m^3) illustrate that the trees planted in the parks in Region C, with a mean volume of 13.56 m^3, had a larger volume than the trees planted in parks in Region D, with a mean volume of 6.14 m^3. The trees planted in the streets in Region D, with a mean volume of 9.18 m^3, had a larger volume than the trees planted in the streets in Region C, with a mean volume of 3.79 m^3. The SE of the volume of the different regions ranges from 0.82 to 3.43. The SE for both the street and park trees is more than 10% of the mean, indicating that the sample variation is high with many outliers. The volume of the trees in Region C is significantly different, but that of the trees in Region D is not significantly different. However, the volume of the trees in Region C is significantly different from that of the trees in Region D.

The results for CGL (mm) show that the park trees in Region C, with a mean CGL of 535.01 mm, had a wider CGL than the park trees in Region C, with a mean CGL of 439.58 mm (Table 5.8). The street trees in Region C, with a mean CGL of 417.13 mm, had a wider mean CGL than the street trees in Region D, with a mean CGL of 289.81 mm. The SE of the CGL of the street and park trees ranges from 14.31 to 38.34. The SE for both the street and park trees is less than 10% of the mean, revealing that the sample variation is low. The CGL of the street and park trees in Region D and the park trees in Region C is not significantly different, but that of the street and park trees in Region D is significantly different from the street trees in Region C.

The results for CBH (mm), seen in Table 5.8, indicate that the park trees in Region C, with a mean CBH of 373.45 mm, had a wider CBH than the park trees in Region D, with a mean CBH of 350.44 mm. The street trees in Region D, with a mean CBH of 294.46 mm, had a wider CBH than the street trees in Region C, with a mean CBH of 194.74 mm. The SE of the CBH of the street and park trees ranges from 13.71 to 28.71. The SE for both the street and park trees is less than 10% of the mean, illustrating that the sample variation is low. The results reveal that the CBH of the street and park trees in Region C are significantly different from the street and park trees in Region D.

5.3.5 Analysis of growth parameters of *Searsia lancea* trees on medians and sidewalks in streets and parks in Region C

Results for the comparison of the growth parameters of *S. lancea* are presented for each growth parameter (Table 5.9).

The results for tree height (m), seen in Table 5.9, indicate that the trees planted on the medians in Region C, with a mean height of 3.69 m, were taller than the trees on sidewalks, with a mean height of 2.98 m and the trees in parks, with a mean height of 2.71 m. The SE values of the tree heights range from 0.10 to 0.13, which is less than 10% of the mean, illustrating that the sample variation is low. The height of the trees planted on sidewalks is not significantly different from that of the trees planted in the parks, but the height of the sidewalk and park trees is significantly different from that of the trees planted on medians.

The results for height of maximum canopy diameter (m), seen in Table 5.9, demonstrate that the median trees in Region C, with a mean height of maximum canopy diameter of 2.47 m, had a higher maximum canopy diameter than the park trees, with a mean height of maximum canopy diameter of 1.99 m, and the sidewalk trees, with a mean height of maximum canopy diameter of 1.80 m. The SE of the height of maximum canopy diameter ranges from 0.07 to 0.09, which is less than 10% of the mean, indicating that the sample variation is low. The height of maximum canopy diameter of the sidewalk trees is not significantly different from that of the park trees, but the height of maximum canopy diameter of the park trees and the sidewalk trees is significantly different from that of the trees planted on the medians.

The results for height at first leaf (m) indicate that the trees planted on the median in Region C, with a mean maximum height at first leaf of 1.20 m, had the highest first leaf (Table 5.8). The height at first leaf of the trees planted in parks, with a mean maximum height at first leaf of 1.08 m, and the height at first leaf of the trees planted on the sidewalk, with a mean maximum height at first leaf of 1.02 m, were lower. The SE of the height at first leaf for the trees ranges from 0.06 and 0.07, which is less than 10% of the mean, showing that the sample variation is low. The height at first leaf of the trees planted on the sidewalks, in parks and on the medians in Region C is not significantly different.

The results for maximum canopy diameter (m), seen in Table 5.9, show that the median trees in Region C, with a mean maximum canopy diameter of 3.00 m, had a wider diameter than both the sidewalk trees, with a mean canopy diameter of 2.13 m, and the park trees (2.04 m).

Table 5.9: Comparison of growth parameters of Searsia lancea *between medians and sidewalks in streets and parks in Region C10*

Land use	Tree height (m)	Height max canopy diameter (m)	Height at first leaf (m)	Max canopy diameter (m)	Stem diameter at first leaf (m)	Canopy volume (m^3)	CGL	CBH
Median	3.69±0.13a	2.47±0.09a	1.20±0.06a	3.00±0.16a	0.35±0.01a	9.87±1.38a	597.50±18.55a	451.12±13.80a
Park	2.98±0.11b	1.99±0.07b	1.08±0.07a	2.04±0.08b	0.30±0.01b	3.45±0.47b	393.00±11.48b	293.35±14.39b
Sidewalk	2.71±0.10b	1.80±0.08b	1.02±0.07a	2.13±0.10b	0.30±0.01b	3.51±0.46b	319.45±10.99b	256.91±12.37b

Mean values (M±S.E) with different letters (a, b) in a column are significant at p ≤ 0.05.

The SE of the maximum canopy diameter ranges from 0.10 to 0.16, which is less than 10% of the mean, illustrating that the sample variation is low. In Region C, the maximum canopy diameter of the sidewalk trees and the park trees is not significantly different, but the maximum canopy diameter of the sidewalk and the park trees is significantly different from that of the median trees.

The results for stem diameter at first leaf (m) indicate that the trees planted on the median in Region C, with a mean stem diameter of 0.35 m, had the widest stem diameter at first leaf and the trees planted on the median and sidewalk, both with a mean stem diameter of 0.30 m, had the smallest (Table 5.9). The SE of the stem diameter at first leaf for the trees planted in the different locations is 0.01, which is less than 10% of the mean, demonstrating that the sample variation is low. In Region C, the stem diameter at first leaf of the trees planted on sidewalks and in parks is not significantly different, but the stem diameter at first leaf of the trees planted on sidewalks and in parks is significantly different from that of the trees planted on medians.

The results for volume (m^3), seen in Table 5.9, indicate that the median trees in Region C, with a mean volume of 9.87 m^3, had a larger volume than the park trees, with a mean volume of 3.45 m^3, and the sidewalk trees, with a mean volume of 3.51 m^3. The SE of the volume of the trees planted in the different locations ranges from 0.46 to 1.38. The SE for the sidewalk, park and median trees is above 10% of the mean, indicating a high sample variation with outliers. In Region C, the volume of the sidewalk trees and the park trees is not significantly different, but the volume of the sidewalk and park trees is significantly different from that of the trees planted on medians.

The results for CGL (mm) demonstrate that the trees planted on the medians in Region C, with a mean CGL of 597.50 mm, had a wider CGL than the trees planted in the parks, with a mean CGL of 293.35 mm, and the trees planted on the sidewalks, with a mean CGL of 319.45 mm (Table 5.9). The SE of the CGL of the trees planted on the sidewalks, parks and medians ranges from 10.99 to 18.55. The SE for both the sidewalk and median trees is less than 10% of the mean, indicating that the sample variation is low. In Region C, the CGL of the trees planted on sidewalks and in parks is not significantly different, but the CGL of the trees planted on sidewalks and in parks is significantly different from that of the trees planted on medians.

The results for CBH (mm) indicate that the median trees in Region C, with a mean CBH of 451.12 mm, had a wider CBH than the park trees, with a mean CBH of 293.35 mm, and the median trees, with a mean CBH of 256.91 mm. The SE of the CBH of the trees planted in the different locations ranges from 12.37 to 14.39. The SE for both the sidewalk and the median trees is less than 10% of the mean, revealing that the sample variation is low. In Region C, the CBH of the sidewalk and park trees is not significantly different, but the CBH of the sidewalk and park trees is significantly different from that of the trees planted on medians.

5.3.6 Analysis of growth parameters of *Olea europaea subsp. africana* trees on sidewalks in streets and parks in Region C

No *O. europaea subsp. africana* trees were found on medians in Region C. Therefore, the results for the comparison of the growth parameters of this tree species in Region C are presented only for sidewalks in streets and parks and for each growth parameter (Table 5.10).

The results for tree height (m) show that the trees planted in the parks in Region C, with a mean height of 3.026 m, were taller than the trees planted on the sidewalks, with a mean height of 2.72 m. The SE values of the tree heights range from 0.13 to 0.14, which is less than 10% of the mean, indicating that the sample variation is low. The height of the trees planted in parks is significantly different from that of trees planted on sidewalks in Region C, as seen in Table 5.10.

The results for height of maximum canopy diameter (m) illustrate that the trees planted in parks in Region C, with a mean height of maximum canopy diameter of 1.84 m, had a higher maximum canopy diameter than the trees on the sidewalks, with a mean height of maximum canopy diameter of 1.83 m (Table 5.10). The SE of the height of maximum canopy diameter ranges from 0.07 to 0.14, which is less than 10% of the mean, showing that the sample variation is low. The height of maximum canopy diameter of the trees planted in the streets is not significantly different from that of trees planted in parks.

The results for height at first leaf (m), seen in Table 5.10, indicate that the park trees in Region C, with a mean maximum height at first leaf of 1.18 m, had a higher first leaf than the sidewalk trees, with a mean height at first leaf of 0.83 m. The SE of the height at first leaf for the trees ranges from 0.05 to 0.08, which is less than 10% of the mean, showing that the sample variation is low. The height at first leaf of the park trees is significantly different from that of the sidewalk trees in Region C.

The results for maximum canopy diameter (m) indicate that the trees planted in the parks in Region C, with a mean maximum canopy diameter of 2.41 m, had a wider canopy diameter than the trees planted on the sidewalks, with a mean canopy diameter of 2.27 m (Table 5.10). The SE of the maximum canopy diameter ranges from 0.13 to 0.16, which is less than 10% of the mean, demonstrating that the sample variation is low. The maximum canopy diameter of the trees planted on sidewalks and that of the trees planted in parks are not significantly different in Region C.

Table 5.10: Comparison of growth parameters of Olea europaea subsp. africana *between parks and sidewalks in streets in Region C*

Land use	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Canopy volume (m^3)**	**CGL**	**CBH**
Park	3.02±0.13a	1.84±0.07a	1.18±0.05a	2.41±0.13a	0.11±0.01a	5.29±0.82a	357.72±21.60b	244.64±14.00b
Sidewalk	2.72±0.14b	1.83±0.14a	0.83±0.08b	2.27±0.16a	0.09±0.01a	4.68±0.88b	448.79±17.11a	299.64±26.22a

Mean values (M±S.E) with different letters (a, b) in a column are significant at p ≤ 0.05.

The results for stem diameter at first leaf (m), seen in Table 5.10, indicate that the park trees in Region C, with a mean stem diameter at first leaf of 0.11 m, had a wider stem diameter at first leaf than the sidewalk trees, with a mean stem diameter of 0.09 m. The SE of the stem diameter at height of first leaf ranges from 0.01 to 0.10, which is less than 10% of the mean, showing that the sample variation is low The stem diameter at first leaf of the trees planted in parks and that of trees planted on sidewalks in Region C are not significantly different.

The results for volume (m^3) indicate that the trees planted in the parks in Region C, with a mean volume of 5.29 m^3, had a larger volume than the trees planted on sidewalks, with a mean volume of 4.68 m^3 (Table 5.10). The SE of the volume of the trees in parks and on sidewalks ranges from 0.82 to 0.88. The SE for both the street and park trees is more than 10% of the mean, illustrating that the sample variation is high with many outliers. The volume of the trees in parks is significantly different from that of trees on sidewalks in Region C.

The results for CGL (mm), seen in Table 5.10, demonstrate that the sidewalk trees in Region C, with a mean CGL of 448.79 mm, had a wider CGL than the sidewalk trees in Region C, with a mean CGL of 357.72 mm. The SE of the CGL of the sidewalk and park trees ranges from 17.11 to 21.60. The SE for the sidewalk and park trees is less than 10% of the mean, showing that the sample variation is low. The CGL of the trees planted on the sidewalks is significantly different from that of the trees planted in the parks in Region C.

The results for CBH (mm) show that the trees planted on the sidewalks in Region C, with a mean CBH of 299.64 mm, had a wider CBH than the trees planted in the parks in Region C, with a mean CBH of 244.64 mm (Table 5.10). The SE of the CBH of the trees planted on the sidewalks and in the parks ranges from 14.00 to 26.22. The SE for both the sidewalk and park trees is less than 10% of the mean, indicating that the sample variation is low. The CBH of the trees planted on the sidewalks is significantly different from those planted in the parks in Region C.

5.3.7 Analysis of growth parameters of *Olea europaea* subsp. *africana* trees on medians in streets and parks in Region D

Olea europaea subsp. *africana* trees were found only on medians and in parks in Region D. None of these trees were found on sidewalks in this region. Therefore, the comparison of the growth parameters of this species is between medians and parks and is presented for each growth parameter (Table 5.11).

The results for tree height (m) demonstrate that the trees planted in the parks in Region D, with a mean height of 3.18 m, were taller than the trees planted on the medians, with a mean height of 2.67 m. The SE values of the tree heights range from 0.07 to 0.15, which is less than

Table 5.11: Comparison of growth parameters of Olea europaea subsp. africana *between parks and medians in streets in Region D*

Land use	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Volume (m^3)**	**CGL**	**CBH**
Median	2.67±0.07b	1.73±0.09b	0.88±0.08b	1.99±0.15b	0.08±0.01a	3.25±0.46b	329.41±9.25b	207.47±7.82b
Park	3.18±0.15a	2.17±0.12a	1.34±0.09a	2.85±0.19a	0.17±0.02a	7.33±1.12a	513.82±30.15a	360.58±26.58a

Mean values (M±S.E) with different letters in a column are significant at p ≤ 0.05.

10% of the mean, indicating that the sample variation is low. The height of the trees planted in parks is significantly different from that of trees planted on medians in Region D, as seen in Table 5.11.

The results for height of maximum canopy diameter (m) illustrate that the park trees in Region D, with a mean height of maximum canopy diameter of 2.17 m, had a higher maximum canopy diameter than the median trees, with a mean height of maximum canopy diameter of 1.73 m (Table 5.11). The SE of the height of maximum canopy diameter ranges from 0.09 to 0.12, which is less than 10% of the mean, indicating that the sample variation is low. The height of maximum canopy diameter of the trees planted on the medians is significantly different from that of trees planted in parks.

The results for height at first leaf (m) show that the trees planted in the parks in Region D, with a mean height at first leaf of 1.34 m, had a higher first leaf than the trees planted on medians, with a mean height at first leaf of 0.88 m. The SE of the mean height at first leaf for the park and median trees ranges from 0.09 to 0.08, which is less than 10% of the mean, illustrating that the sample variation is low. The height at first leaf of the park trees is significantly different from that of the median trees in Region D, as seen in Table 5.11.

The results for maximum canopy diameter (m) show that the trees planted in the parks in Region D, with a mean maximum canopy diameter of 2.85 m, had a wider mean diameter than those planted on the medians, with a mean diameter of 1.99 m (Table 5.11). The SE of the maximum canopy diameter ranges from 0.15 to 0.19, which is less than 10% of the mean, demonstrating that the sample variation is low. The maximum canopy diameter of the trees planted on sidewalks is significantly different from that of the trees planted in parks in Region D.

The results for stem diameter at first leaf (m) indicate that the park trees in Region D, with a mean stem diameter at first leaf of 0.17 m, had a wider stem diameter at first leaf than the trees planted on the medians, with a mean diameter of 0.17 m (Table 5.11). The SE of the stem diameter at first leaf ranges from 0.01 to 0.02, which is more than 10% of the mean, showing that the sample variation is high with outliers. The stem diameter at first leaf of the trees planted in parks is significantly different from those planted on sidewalks in Region D.

The results for volume (m^3) indicate that the trees planted in the parks in Region D, with a mean volume of 5.29 m^3, had a larger volume than the trees planted on sidewalks, with a mean volume of 4.68 m^3. The SE of the volume of the trees in parks and on sidewalks ranges from 0.82 to 0.88. The SE for both the street and park trees is more than 10% of the mean, indicating that the sample variation is high with many outliers. The volume of the trees in parks is significantly different from those on sidewalks in Region D, as can be seen in Table 5.11.

The results for CGL (mm) indicate that the trees planted in the parks in Region D, with a mean CGL of 513.82 mm, had a wider CGL than the trees on the medians, with a mean CGL of 329.41 mm

(Table 5.11). The SE of the CGL of the trees planted in the streets and parks ranges from 9.25 to 30.15. The SE for the trees planted on medians and in parks is less than 10% of the mean, showing that the sample variation is low. The CGL of the trees planted on the medians is significantly different from those planted in parks in Region D.

The results for CBH (mm) demonstrate that the park trees in Region D, with a mean CBH of 360.58 mm, had a wider CBH than the median trees in Region D, with a mean CBH of 207.47 mm. The SE of the CBH of the median and park trees ranges from 7.82 to 26.58. The SE for both the median and park trees is less than 10% of the mean, showing that the sample variation is low. The CBH of the trees planted on the medians is significantly different from those planted in the parks in Region D.

5.3.8 Discussion: Growth parameter comparisons between sidewalks, medians, streets and parks

The comparison of the growth parameters of *C. africana* on medians and sidewalks in streets in Region C in the CoJ indicates that the trees planted on the sidewalks were taller than the trees on medians, their mean height of maximum canopy diameter was higher, their height at first leaf was higher, their maximum canopy diameter was wider, their stem diameter at first leaf was wider and their volume was larger. The results also show that the CGL and the CBH of the *C. africana* trees were wider for the trees planted on sidewalks than for those on medians. Except for the results of the height at first leaf growth parameter, all the results were significant. The reason for the insignificance of the height at first leaf results could be the lack of pruning of these trees. No crown lifting or structured pruning was observed during the field surveys, and this results in inconsistent heights of crowns when measured at the first leaf from the ground. When the trees planted in the streets (sidewalks and medians) are compared with those planted in parks, the results for the *C. africana* trees show that the trees in parks were taller than those in streets in Regions C and D. For the trees planted in parks, the mean maximum canopy diameter was wider, their height at first leaf was higher, their stem diameter at height of first leaf was wider and their volume was larger than trees planted in streets. However, the maximum canopy diameter of *C. africana* trees planted in streets was wider than that of trees planted in parks. The CGL and the CBH of the *C. africana* trees were wider for the trees planted in parks than in streets. There was no significant difference between the growth parameters (height at first leaf and maximum canopy diameter) of the street and park trees in Regions C and D. These results could be influenced by the lack of pruning of the canopy of the trees; the lack of pruning and crown management was visible during field surveys. The results for the stem diameter at first leaf were also not significant in the parks in Regions C and D. The results of the remaining parameters were significant. Therefore, *C. africana* trees grow better in parks than in streets, and in streets they grow better on sidewalks than on medians. They should therefore preferably be planted in parks, but if they are planted in streets, it is suggested that they be planted on sidewalks.

The comparison of the growth parameters of *C. erythrophyllum* on medians and sidewalks in streets in Region D illustrates that the trees planted on the medians were taller, their height of maximum canopy diameter was higher and their height at first leaf was higher than those planted on sidewalks. The results for maximum canopy diameter indicate that the trees planted on sidewalks in Region D had a wider diameter, their stem diameter at first leaf was wider and the volume of the trees was larger than the trees planted on the medians. The CGL and the CBH of the *C. erythrophyllum* trees were wider for the trees planted on sidewalks than on medians. The results of all the growth parameters, except for CGL and CBH, were not significantly different, showing that the growth of *C. erythrophyllum* is not significantly different if planted on sidewalks or medians in streets. Therefore, there is no preference for planting these trees on sidewalks or medians and they would grow well in both locations. When the trees planted in the streets (sidewalks and medians) are compared with those planted in parks, the results for the *C. erythrophyllum* trees indicate that the trees in parks were taller, their height of maximum canopy diameter was higher, the first leaf was higher, the maximum canopy diameter was wider, the volume was larger and both the CGL and CBH were wider than the trees planted in streets in Region C. The results were significant, showing that the preferred location to plant *C. erythrophyllum* in Region C would be parks. However, except for CGL and CBH, all the other growth parameters indicate that *C. erythrophyllum* trees grow higher with a wider canopy in the streets compared to the parks in Region D. These results indicate that there is a significant difference in the tree height, height of maximum canopy diameter, height at first leaf and stem diameter at first leaf, but no significant difference in maximum canopy diameter, volume and CGL and CBH measurements. Therefore, the results reveal that even though *C. erythrophyllum* trees grow taller and wider in streets than in parks, the results are not always significant, showing that this species will do well in either streets or parks in the region. The results of most of the growth parameters of *C. erythrophyllum* between Regions C and D were not significantly different, indicating that this tree species grows well in both regions.

The comparison of the growth parameters of *S. lancea* on medians and sidewalks in streets and parks in Region C indicates that for all the growth parameters in the study, the trees planted on medians had larger measurements and a wider canopy than those planted in parks and on sidewalks. Except for maximum canopy diameter, stem diameter at first leaf and volume, trees planted in parks had larger measurements than trees planted on the sidewalk. This indicates a significant difference in all the growth parameters of the median and park trees, but no significance difference in the results between the park and sidewalk trees. These results indicate that *S. lancea* trees grow very well on medians and this location should be the preferred location for this tree species. The second-best location should be in parks and lastly on sidewalks.

The comparison of the growth parameters of *O. europaea* subsp. *africana* trees on sidewalks in streets and parks in Region C shows that for all the growth parameters, the trees planted in parks had larger measurements than those on sidewalks, except for height of maximum canopy diameter, maximum canopy diameter and the stem diameter at first leaf. All the other growth parameter results were significant. Therefore, it is advised that *O. europaea* subsp*. africana* preferably be planted in parks.

5.4 Growth parameter relationships

"Information on urban tree growth underpins models used to calculate the effects of trees on the environment" (McPherson et al., 2016). Growth equations contain two components: a time-related component (tree age) and a growth expansion component age relative to the growth parameters. Due to the genetic traits of individual tree species and their responses to the environment and management, a single growth equation cannot be used for all tree species (McPherson et al., 2016). Therefore, the growth parameter data from VolCalc was used to develop growth equations for the trees in this study. The aim was to determine the best growth parameters to be used to predict growth.

Results for the correlations of the growth parameters are presented in scatter plot diagrams. The CBH/CGL correlations are shown in Figures 5.2 to 5.5 and the different growth relationship correlations are presented in Figures 5.6 to 5.53. In all these figures the estimated mean response or trendline and the R^2 descriptor are indicated and the CGL and CBH are independent variables. The relationship between the growth parameters and time is presented in Figures 5.54 to 5.61. In these figures trendlines are indicated and age is the independent variable.

5.4.1 Growth relationship between CGL and CBH for all four tree species

Results demonstrate that there is a strong correlation between CGL and CBH for all four tree species. The R^2 value for *C. africana* is 0.8884 (Figure 5.2), for *C. erythrophyllum* it is 0.9058 (Figure 5.3), for *S. lancea* it is 0.8154 (Figure 5.4) and for *O. europaea* subsp. *africana* it is 0.8121 (Figure 5.5). The trendline in all cases is positive and linear and the bulk of the data points are very close to the trendline, with very few data points scattered further from the trendline. The positive relationship implies that increases in CBH are associated with corresponding increases in CGL, as shown in the linear equation indicated in the top right-hand corner of all the figures. For the tree with the highest R^2 value (*C. erythrophyllum* R^2 0.9058), the data from 80 mm CGL value and 57 mm CBH value above the line to 956 mm CGL value and 1 081 mm CBH value below the line. For the tree with the weakest R^2 value (*O. europaea* subsp*. africana* R^2 – 0.8121), the data ranges from 795 mm CGL value and 682 mm CBH value above the line to 268 mm CGL value and 129 mm CBH value below the line. The influence in the variation is very small and is due to a few outliers of trees with either very small CBH (39 mm) and wide CGL (428 mm) or small CGL (113 mm) and wider CBH (298 mm) in the sample. It must be noted that even where this evident, the R^2 value is still above 80%.

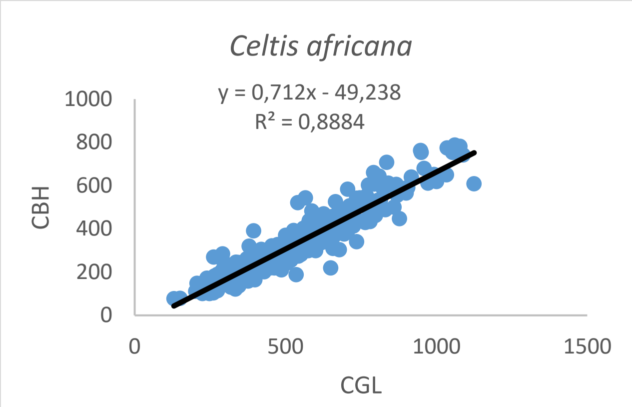


Figure 5.2: Correlation between CBH and CGL for Celtis africana

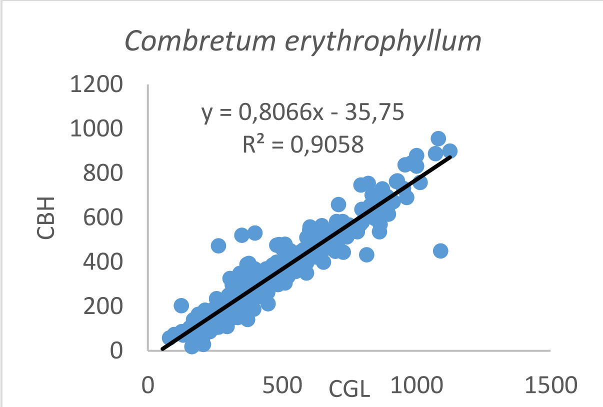


Figure 5.3: Correlation between CBH and CGL for Combretum erythrophyllum

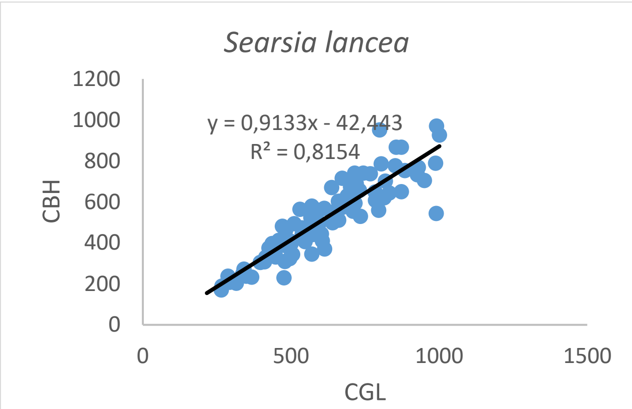


Figure 5.4: Correlation between CBH and CGL for Searsia lancea

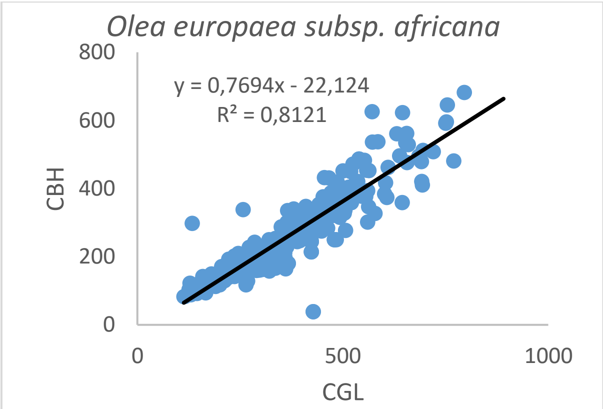


Figure 5.5: Correlation between CBH and CGL for Olea europaea subsp. africana

5.4.2 Relationship of CGL and CBH with tree height for the different tree species

There is a weak correlation between both CGL and tree height and CBH and tree height for *C. africana* (CGL – R^2 0.335 and CBH – R^2 0.306), seen in Figures 5.6 and 5.7. There is a very weak correlation between both CGL and tree height and CBH and tree height for *C. erythrophyllum* (CGL - R^2 0.2128 and CBH - R^2 0.187), seen in Figures 5.8 and 5.9, *O. europaea* subsp. *africana* (CGL - R^2 0.124 and CBH - R^2 0.195), seen in Figures 5.10 and 5.11, and *S. lancea* (CGL - R^2 0.2561 and CBH - R^2 0.0998), seen in Figures 5.12 and 5.13. The tree species with the highest R^2 value for CGL and tree height (0.3354) as well as for CBH and tree height (0.3061) is *C. africana*. The trendline with the best fit for both CGL and CBH with tree height for *C. africana*, *C. erythrophyllum* and *O. europaea* subsp. *africana* is linear and the trendline with the best fit for *S. lancea* is logarithmic. A linear trendline for *S. lancea* provides a weaker correlation between CGL, CBH and tree height (CGL - R^2 0.2383 and CBH - R^2 0.0746) than that of the logarithmic trendline. In all cases, the data points are spread in a dispersed pattern. The R^2 value of the linear trendline is provided in Figures 5.9 and 5.10.

For *C. africana* and *O. europaea* subsp. *africana* CBH is a slightly better predictor of tree height than CGL. However, for *C. erythrophyllum* and *S. lancea* CGL is a slightly better predictor of tree height than CBH.

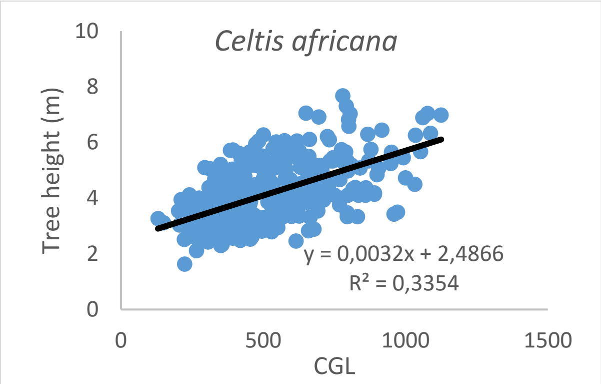


Figure 5.6: CGL and tree height for Celtis africana

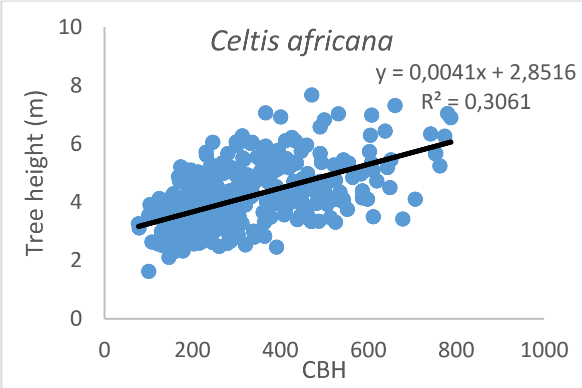


Figure 5.7: CBH and tree height for Celtis africana

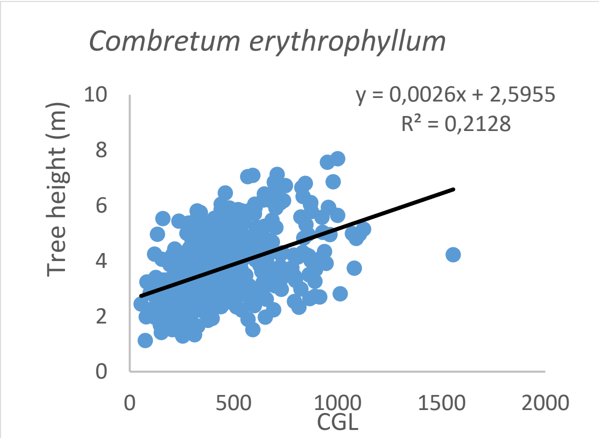


Figure 5.8: CGL and tree height for Combretum erythrophyllum

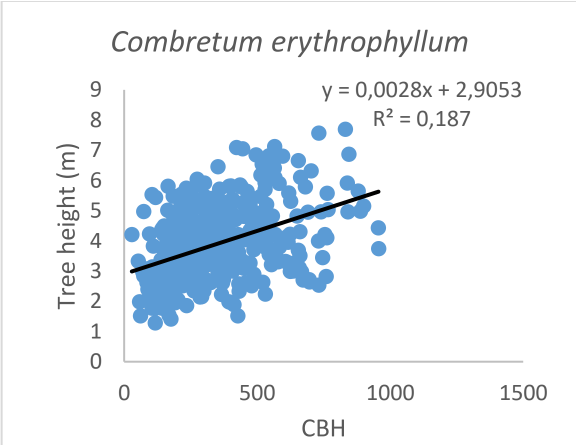


Figure 5.9: CBH and tree height for Combretum erythrophyllum

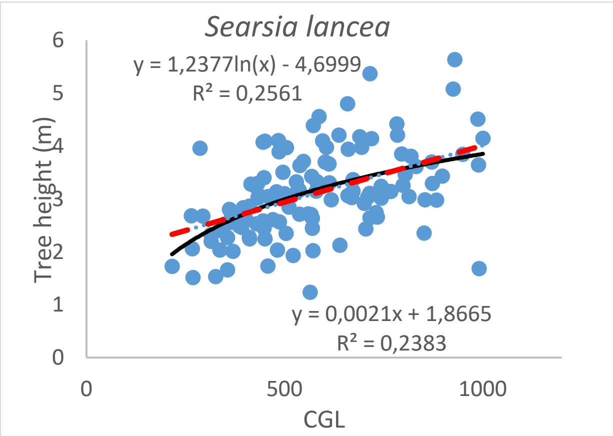


Figure 5.10: CGL and tree height for Searsia lancea

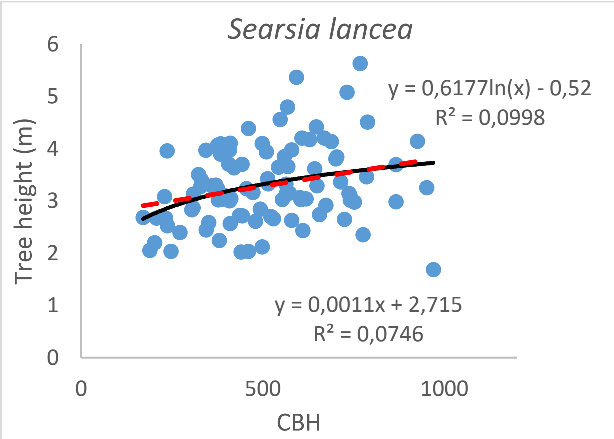


Figure 5.11: CBH and tree height for Searsia lancea

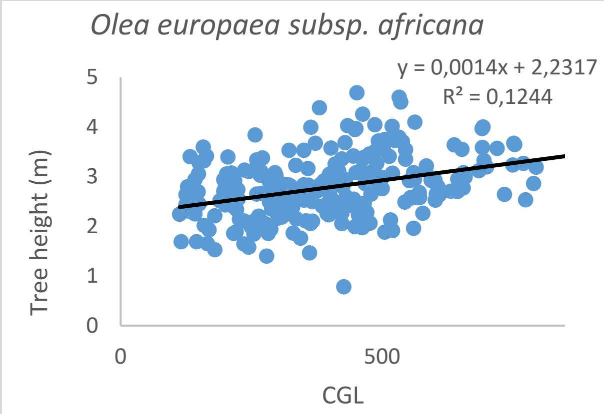


Figure 5.12: CGL and tree height for Olea europaea subsp. africana

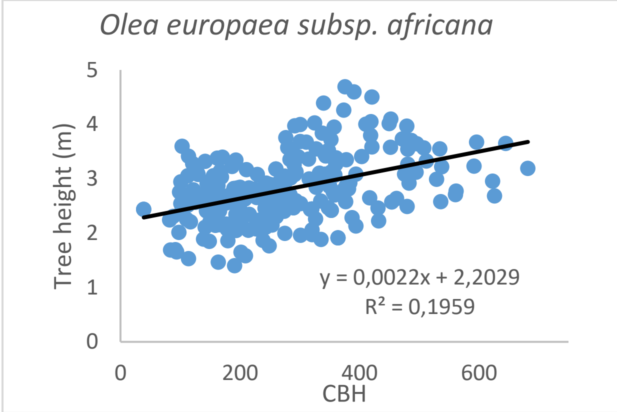


Figure 5.13: CBH and tree height for Olea europaea subsp. africana

5.4.3 Relationship of CGL and CBH with height of maximum canopy diameter for the different tree species

There is a weak correlation between both CGL and height of maximum canopy diameter and CBH and height of maximum canopy diameter for *C. africana* (CGL – R2 0.223 and CBH – R^2 0.218), seen in Figures 5.14 and 5.15. The R^2 values for *C. erythrophyllum* (CGL - R^2 0.174 and CBH - R^2 0.1.369) in Figures 5.16 and 5.17, *S. lancea* (CGL – R^2 0.1321 and CBH – R^2 0.0111) in Figures 5.18 and 5.19 and *O. europaea* subsp*. africana* (CGL - R^2 0.002 and CBH - R^2 0.029) in Figures 5.20 and 5.21 reveal that there is a very weak correlation between both CGL and height of maximum canopy diameter and CBH and height of maximum canopy diameter. The tree species with the highest R^2 value for CGL and height of maximum canopy diameter (0.2235) as well as for CBH and height of maximum canopy diameter (0.2187) is *C. africana*. The trendline with the best fit for both CGL and CBH with height of maximum canopy diameter for *C. erythrophyllum* is a power trendline (Figures 5.16 and 5.17). The R^2 value of the linear trendline (CGL - R^2 0.153 and CBH - R^2 0.1.1178) was less than the power trendline (CGL - R^2 0.174 and CBH - R^2 0.1.369). The power trendlines are indicated in a black line and the linear trendlines are indicated in red dashed lines. A linear trendline is the best fit trendline for the other species. In all cases, the data points are spread in a dispersed pattern in relation to the trendline. The reason for the dispersed pattern and low R^2 value may be the variety of tree heights and stem circumferences of all the tree species as explained above. For *O. europaea* subsp. *africana*, CBH is a slightly better predictor of height of maximum canopy diameter than CGL, but for *C. africana, C. erythrophyllum* and *S. lancea,* CGL is a slightly better predictor of height of maximum canopy diameter than CBH.

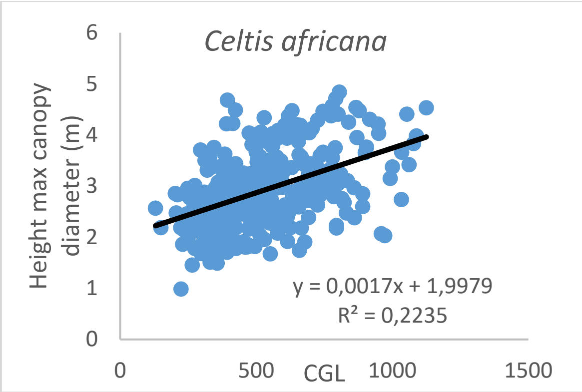


Figure 5.14: CGL and height of maximum canopy diameter for Celtis africana

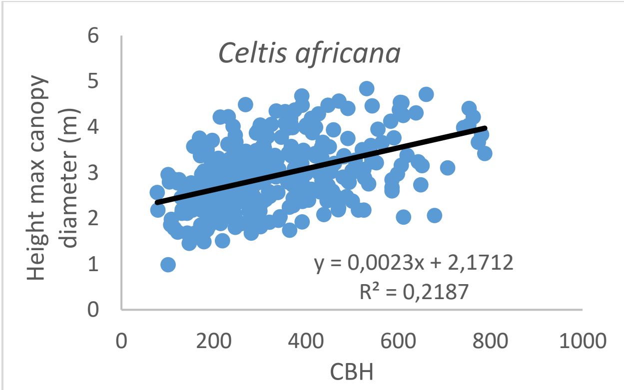


Figure 5.15: CBH and height of maximum canopy diameter for Celtis africana

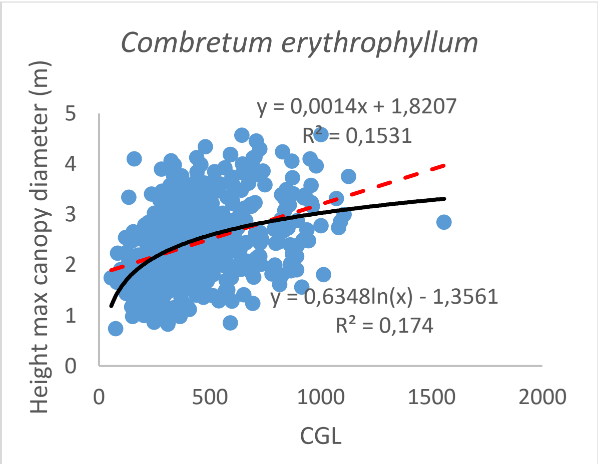


Figure 5.16: CGL and height of maximum canopy diameter for Combretum erythrophyllum

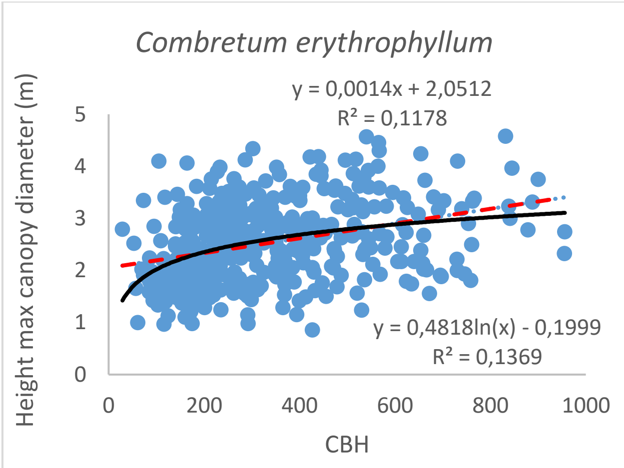


Figure 5.17: CBH and height of maximum canopy diameter for Combretum erythrophyllum

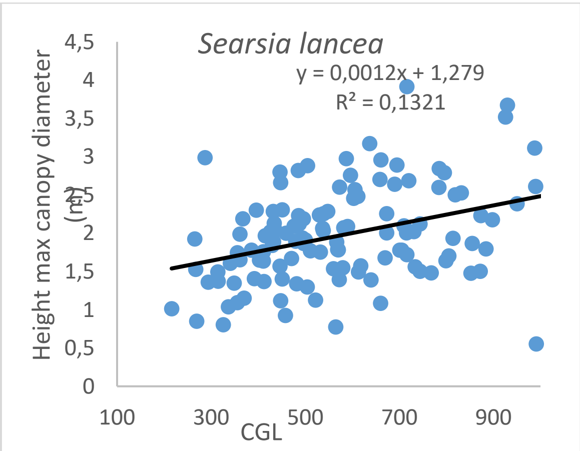


Figure 5.18: CGL and height of maximum canopy diameter for Searsia lancea

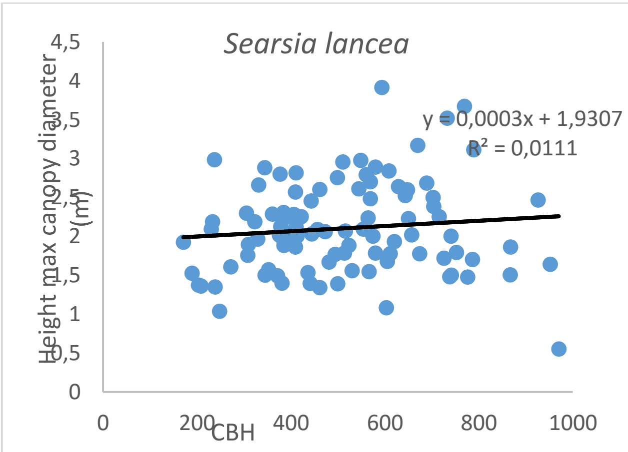


Figure 5.19: CBH and height of maximum canopy diameter for Searsia lancea

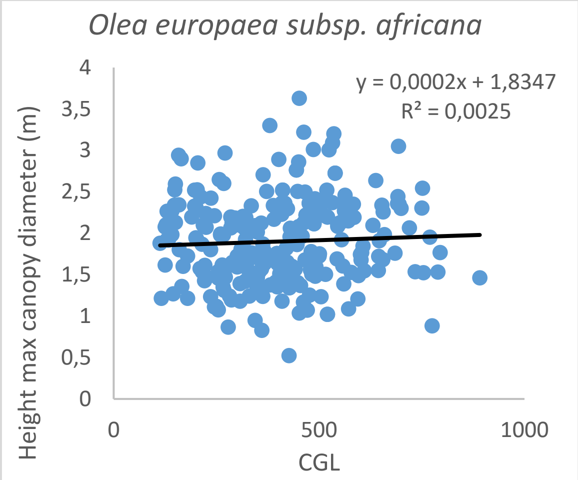


Figure 5.20: CGL and height of maximum canopy diameter for Olea europaea subsp. africana

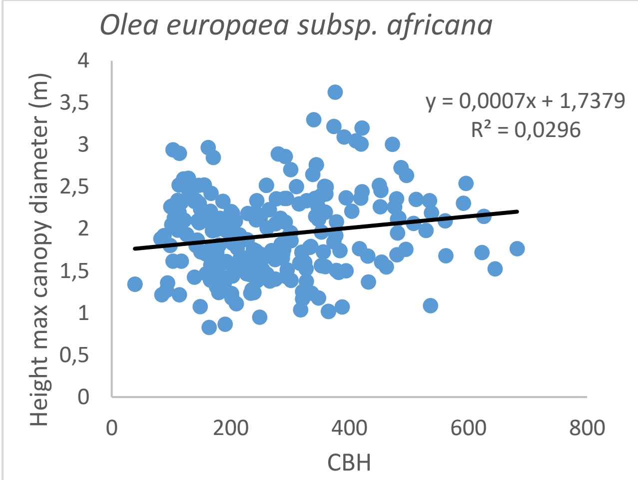


Figure 5.21: CBH and height of maximum canopy diameter for Olea europaea subsp. africana

5.4.4 Relationship of CGL and CBH with height at first leaf

There is a very weak correlation between both CGL and height at first leaf and CBH and height at first leaf for all the tree species. The R^2 values for *C. africana* (CGL – R^2 0.029 and CBH – R^2 0.034) in Figures 5.22 and 5.23, *C. erythrophyllum* (CGL - R^2 0.033 and CBH - R^2 0.007) in Figures 5.24 and 5.25 and *S. lancea* (CGL – R^2 0.074 and CBH – R^2 0.0038) in Figures 5.26 and 5.27 indicate the very weak but positive linear relationship. The R^2 values for *O. europaea* subsp. *africana* (CGL - R^2 0.016 and CBH - R^2 0.072) in Figures 5.28 and 5.29 are also very weak and indicate a negative relationship (or a downhill trend). *O. europaea* subsp. *africana* is the tree species with the highest R^2 value for CGL and height at first leaf (0.116) as well as for CBH and height at first leaf (0.0729). The linear trendline is the best fit for both CGL and CBH with height at first leaf for all the tree species. The trendline is positive for *C. africana, C. erythrophyllum* and CGL and height at first leaf of *S. lancea,* but negative for *O. europaea* subsp. *africana* and CBH and height at first leaf of *S. lancea*. In all cases, the data points are spread in a dispersed pattern in relation to the trendline. Even though the R^2 values are low, they do indicate that CBH is a slightly stronger predictor than CGL for *C. africana* but for *C. erythrophyllum, S. lancea* and *O. europaea* subsp*. africana,* CGL is a slightly better predictor.

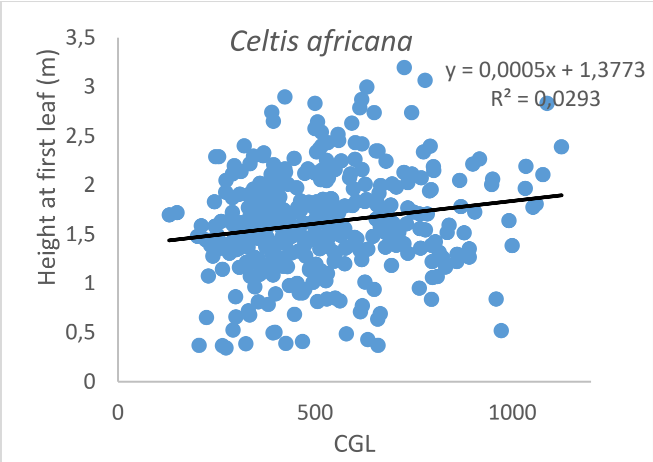


Figure 5.22: CGL and height at first leaf for Celtis africana

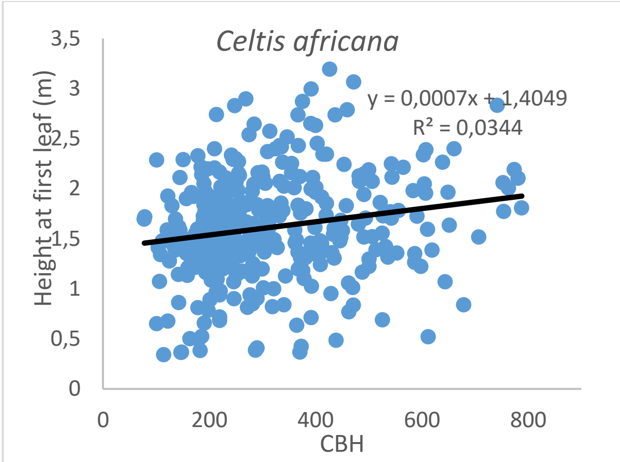


Figure 5.23: CBH and height at first leaf for Celtis africana

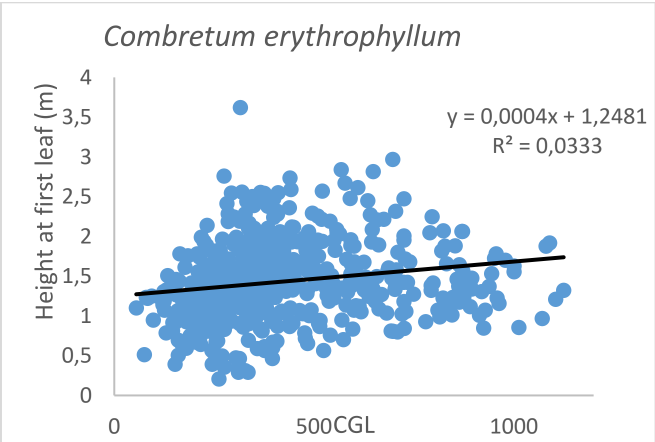


Figure 5.24: CGL and height at first leaf for Combretum erythrophyllum

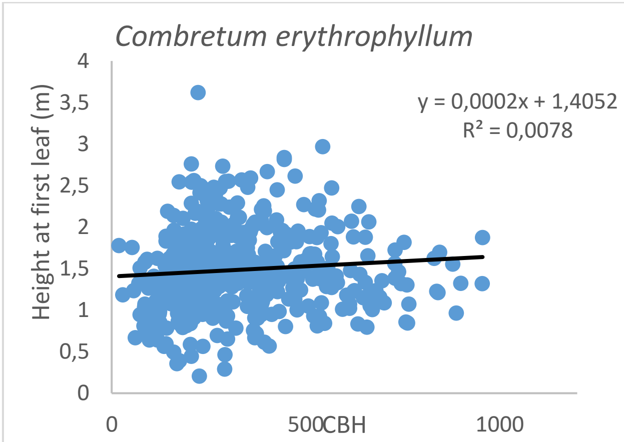


Figure 5.25: CBH and height at first leaf for Combretum erythrophyllum

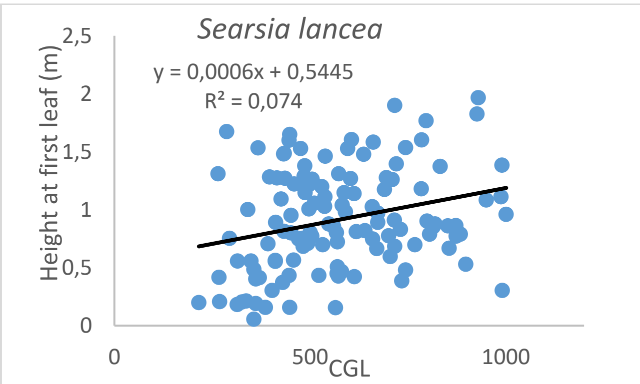


Figure 5.26: CGL and height at first leaf for Searsia lancea

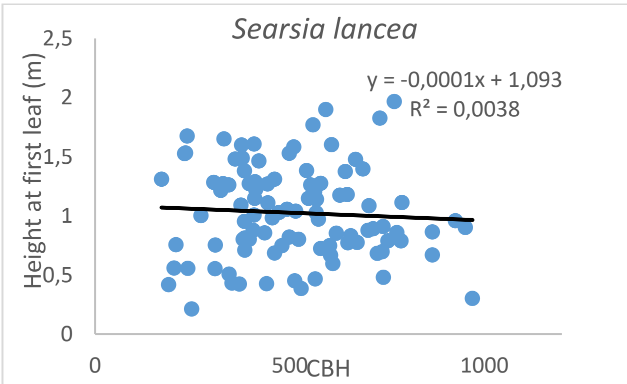


Figure 5.27: CBH and height at first leaf for Searsia lancea

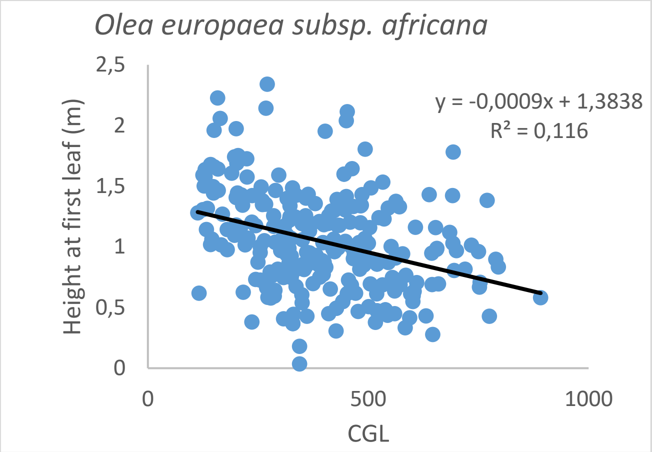


Figure 5.28: CGL and height at first leaf for Olea europaea subsp. africana

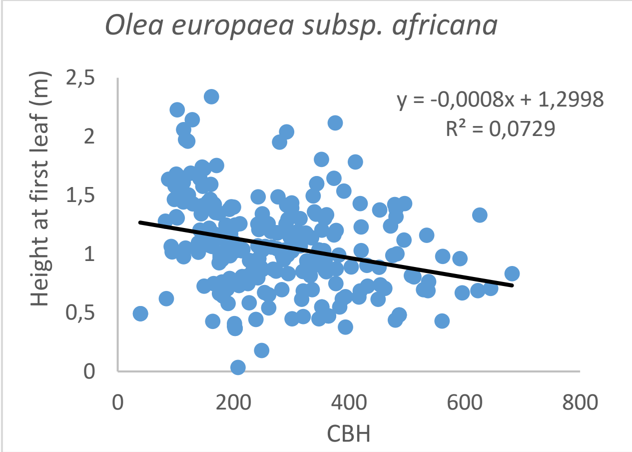
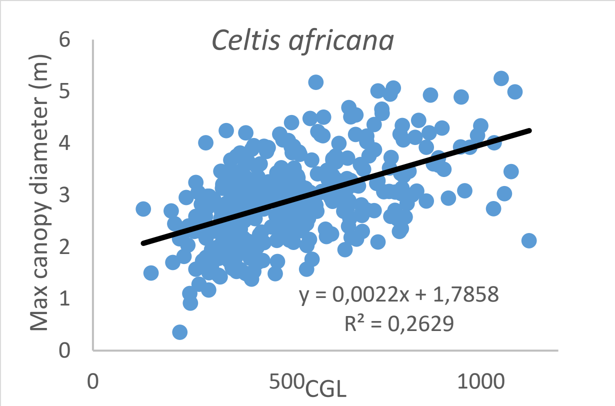


Figure 5.29: CBH and height at first leaf for Olea europaea subsp. africana

5.4.5 Relationship of CGL and CBH with maximum canopy diameter

There is a very weak correlation between both CGL and maximum canopy diameter and CBH and maximum canopy diameter for *C. africana* (CGL – R^2 0.262 and CBH – R^2 0.295), seen in Figures 5.30 and 5.31, for *C. erythrophyllum* (CGL - R^2 0.2605 and CBH – R^2 0.2637), seen in Figures 5.32 and 5.33, and for *S. lancea* (CGL - R^2 0.3828 and CBH – R^2 0.4023), seen in Figures 5.34 and 5.35. The R^2 value for *O. europaea* subsp. *africana* (CGL - R^2 0.504 and CBH R^2 0.533) in Figures 5.36 and 5.37 indicates that there is a moderate correlation between both CGL and maximum canopy diameter and CBH and maximum canopy diameter. *O. europaea* subsp. *africana* is the tree species with the best R^2 value for CGL and maximum canopy diameter (0.5049) and also for CBH and maximum canopy diameter (0.533). The best fitting trendline is linear and the data points are spread in a dispersed pattern in relation to the trendline. The power trendline is the best fit for CBH and maximum canopy diameter for both CBH and CGL and maximum canopy diameter for *S. lancea*. When a linear trendline is applied to the data of *S. lancea,* the R^2 value reduces slightly for CGL and noticeably for CBH (CGL - R^2 0.3612 and CBH R^2 0.3247). Even though the R^2 values are low, they do indicate that for all four tree species CBH is a slightly better predictor of maximum canopy diameter than CGL.



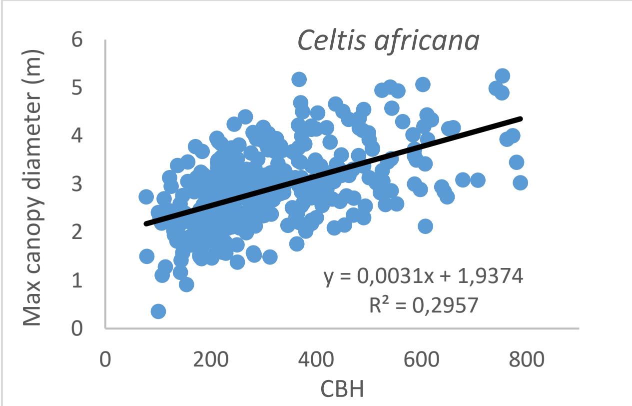
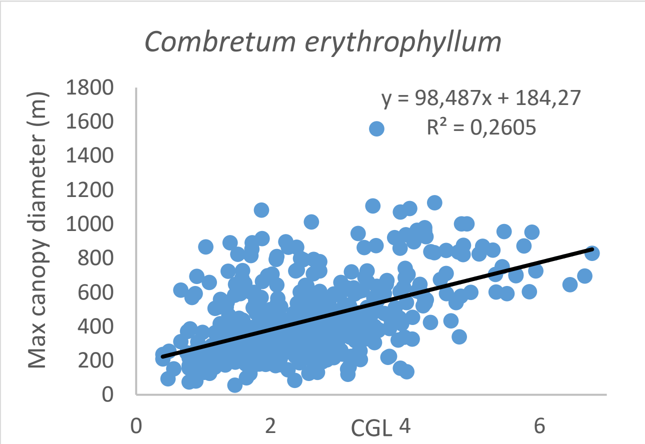


Figure 5.30: CGL and maximum canopy diameter for Celtis africana

Figure 5.31: CBH and maximum canopy diameter for Celtis africana



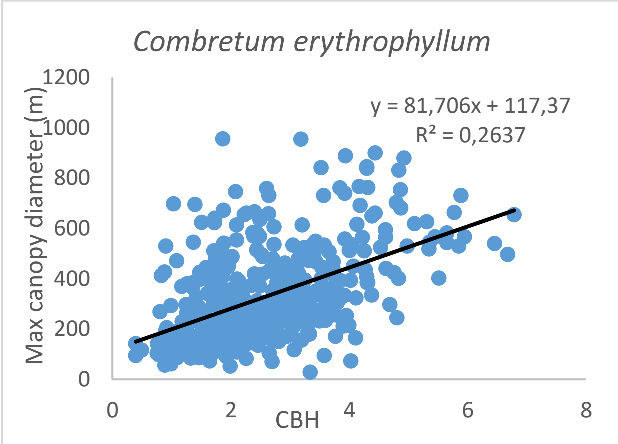
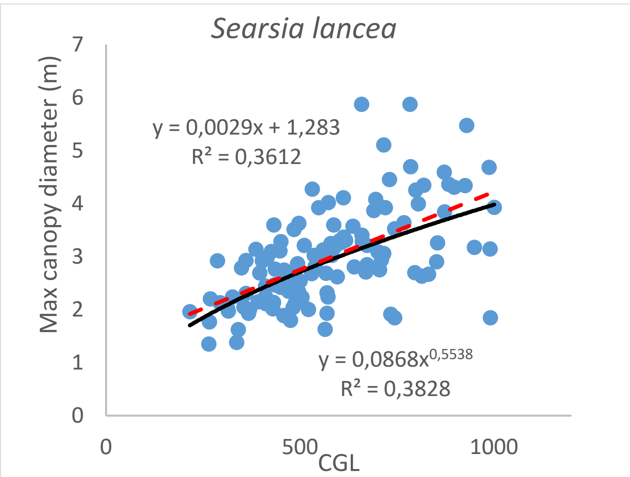


Figure 5.32: CGL and maximum canopy diameter for Combretum erythrophyllum

Figure 5.33: CBH and maximum canopy diameter for Combretum erythrophyllum



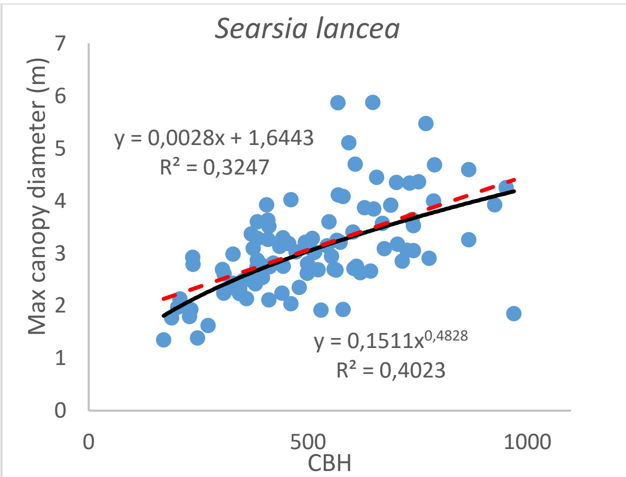


Figure 5.34: CGL and maximum canopy diameter for Searsia lancea

Figure 5.35: CBH and maximum canopy diameter for Searsia lancea

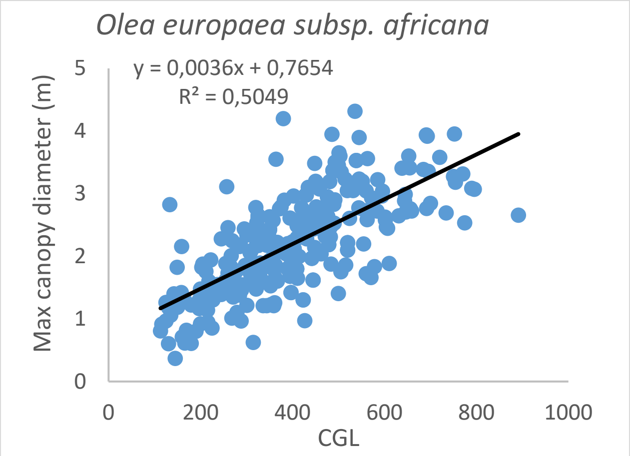


Figure 5.36: CGL and maximum canopy diameter for Olea europaea subsp. africana

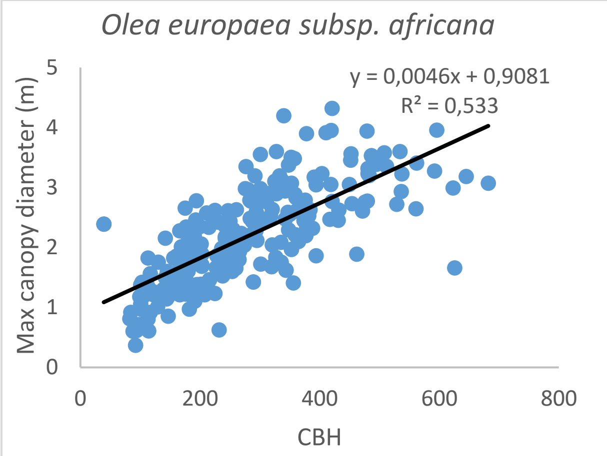


Figure 5.37: CBH and maximum canopy diameter for Olea europaea subsp. africana

5.4.6 Relationship of CGL and CBH with stem diameter at first leaf for the different tree species

There is a weak correlation between both CGL and stem diameter at first leaf and CBH and stem diameter at first leaf for *C. africana* (CGL – R^2 0.383 and CBH – R^2 0.395), seen in Figures 5.38 and 5.39, for *O. europaea* subsp. *africana* (CGL - R^2 0.241 and CBH – R^2 0.20), seen in Figures 5.40 and 5.41, and for *S. lancea* (CGL - R^2 0.3803 and CBH - R^2 0.438), seen in Figures 5.42 and 5.43. There is a very weak correlation between both CGL and stem diameter at first leaf and CBH and stem diameter at first leaf for *C. erythrophyllum* (CGL – R^2 0.1052 and CBH – R^2 0.0729), seen in Figures 5.44 and 5.45. The tree species with the best R^2 value for CGL and stem diameter at first leaf is *C. africana* (0.383) and the tree species with the best R^2 value for CBH and stem diameter at first leaf is *S. lancea* (0.438). The trendline in all cases is linear and the data points are spread in a dispersed pattern in relation to the trendline. Even though the R^2 values are low, they do indicate that for *C. africana* and *S. lancea* CBH is a slightly better predictor than CGL. For *C. erythrophyllum* and *O. europaea* subsp. *africana* CGL is a slightly better predictor than CBH, but in both cases stem diameter at first leaf is not a good predictor of growth (CGL and CBH).

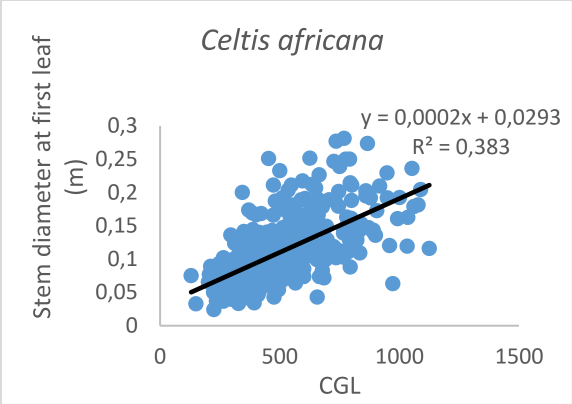


Figure 5.38: CGL and stem diameter at first leaf for Celtis africana

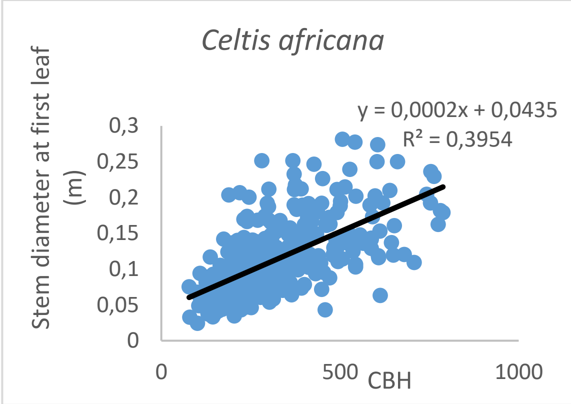


Figure 5.39: CBH and stem diameter at first leaf for Celtis africana

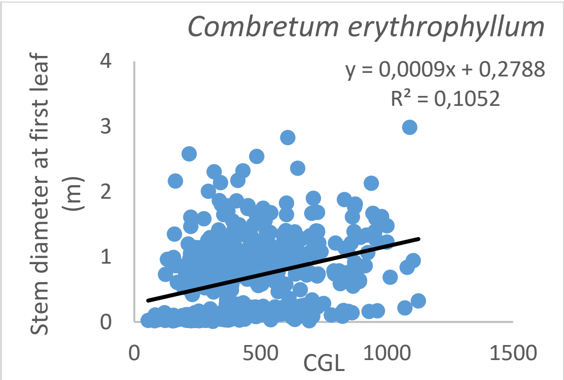


Figure 5.40: CGL and stem diameter at first leaf for Combretum erythrophyllum

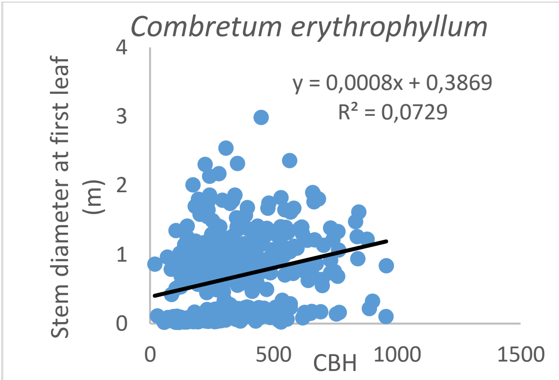


Figure 5.41: CBH and stem diameter at first leaf for Combretum erythrophyllum

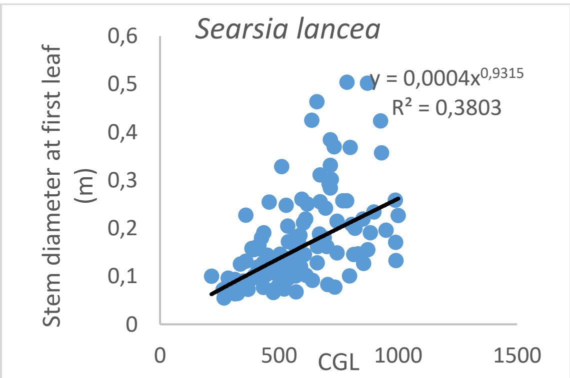


Figure 5.42: CGL and stem diameter at first leaf for Searsia lancea

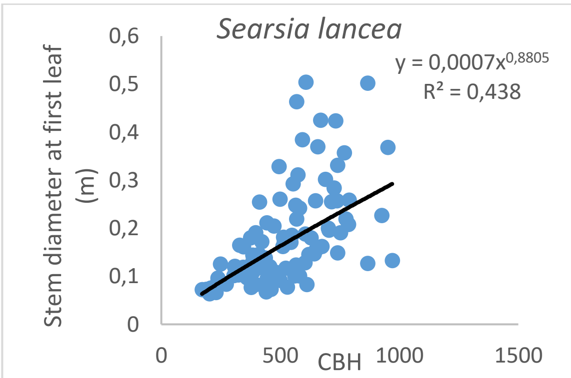


Figure 5.43: CBH and stem diameter at first leaf for Searsia lancea

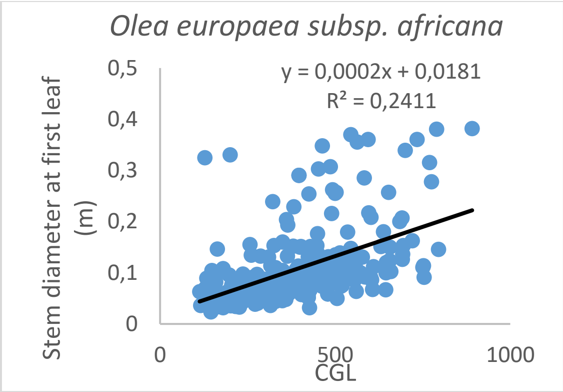


Figure 5.44: CGL and stem diameter at first leaf for Olea europaea subsp. africana

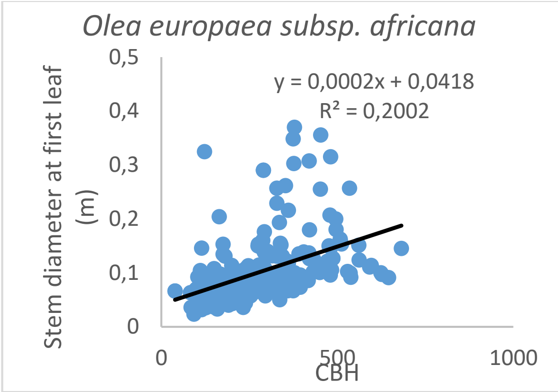


Figure 5.45: CBH and stem diameter at first leaf for Olea europaea subsp. africana

5.4.7 Relationship of CGL and CBH with volume

There is a weak correlation between both CGL and volume and CBH and volume for *C. africana* (CGL – R^2 0.396 and CBH – R^2 0.420), seen in Figures 5.46 and 5.47, for *C. erythrophyllum* (CGL - R^2 0.163 and CBH – R^2 0.154) (Figures 5.48 and 5.49) and *S. lancea* (CGL - R^2 0.4191 and CBH – R^2 0.4363) (Figures 5.50 and 5.51). The R^2 value for *O. europaea* subsp. *africana* (CGL - R^2 0.421 and CBH – R^2 0.483), seen in Figures 5.52 and 5.53, indicates that there is a very weak correlation between both CGL and CBH with volume. The tree species with the best R^2 value for CGL and volume (0.4214) and also for CBH and volume is *O. europaea subsp. africana* (0.4837). The trendline in most cases is linear and the data points are spread in a dispersed pattern in relation to the trendline. The trendline with the best fit for CBH and volume for *C. africana, C. erythrophyllum* and *O. europaea* subsp. *africana* is linear and both CBH and CGL and volume for *S. lancea* is a power trendline. When a linear trendline is applied to the data, the R^2 value reduces (CGL – R^2 0.3931 and CBH – R^2 0.3445). Even though the R^2 values are low, they do indicate that for *C. africana, O. europaea* subsp. *africana* and *S. lancea* CBH is a slightly better predictor of volume than CGL; however, for *C. erythrophyllum* CGL is a slightly better predictor of volume.

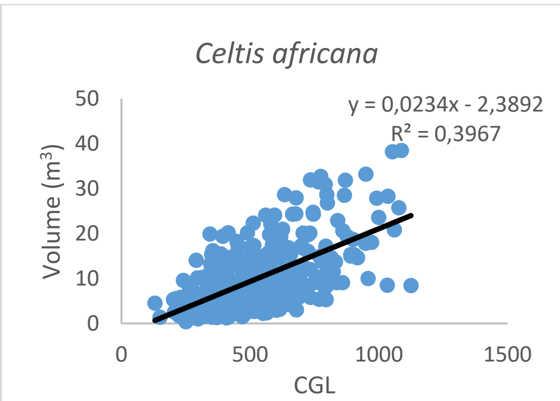


Figure 5.46: CGL and volume for Celtis africana

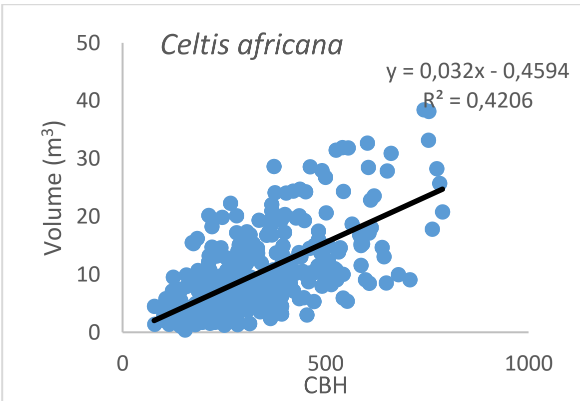


Figure 5.47: CBH and volume for Celtis africana

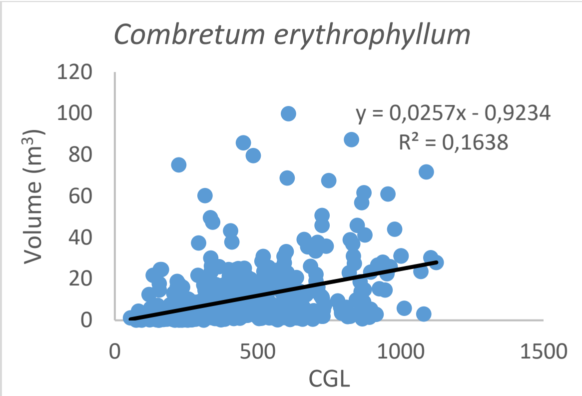


Figure 5.48: CGL and volume for Combretum erythrophyllum

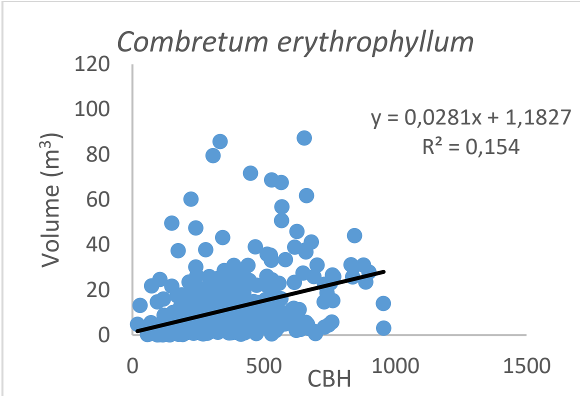


Figure 5.49: CBH and volume for Combretum erythrophyllum

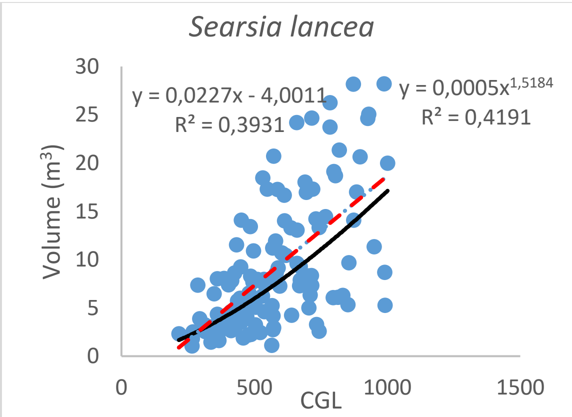


Figure 5.50: CGL and volume for Searsia lancea

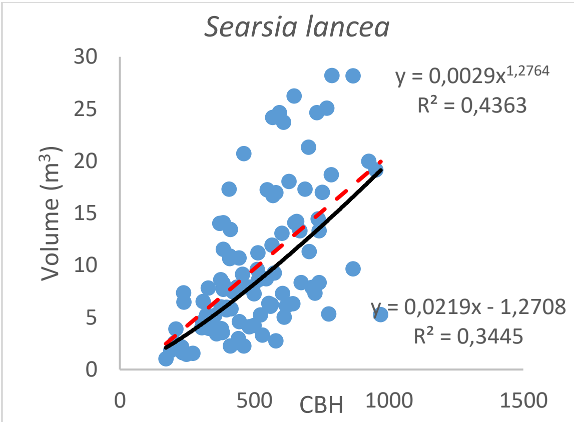


Figure 5.51: CBH and volume for Searsia lancea

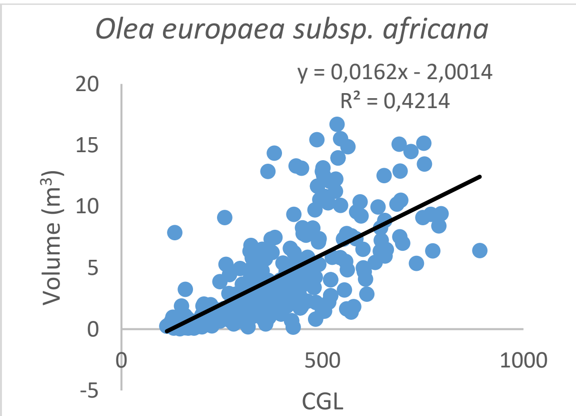


Figure 5.52: CGL and volume for Olea europaea subsp. africana

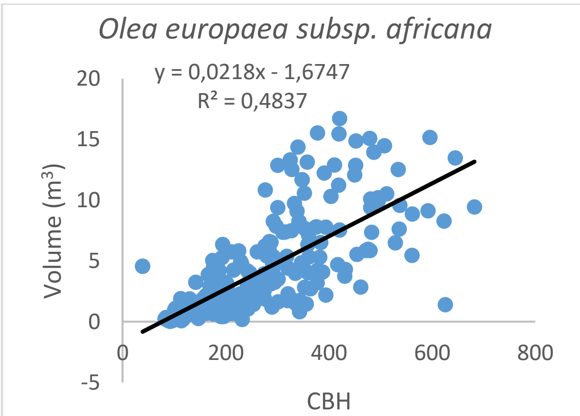


Figure 5.53: CBH and volume for Olea europaea subsp. africana

5.4.8 Relationship of CGL and CBH with age of the trees

There is a very weak correlation between both CGL and tree age and CBH and tree age for all the trees in the study. The results for *C. africana,* seen in Figures 5.54 and 5.55, with a linear trendline registered R^2 of 0.0035 for CGL and R^2 of 0.0032 for CBH. Results for *C. erythrophyllum* (Figures 5.56

and 5.57) with a linear trendline displayed R^2 of 0.0551 for CGL and R^2 of 0.0578 for CBH. The results for *S. lancea* (Figures 5.58 and 5.59) with a linear trendline displayed R^2 of 0.0514 for CGL and R^2 of 0.019 for CBH. The R^2 value for *O. europaea* subsp. *africana* (CGL - R^2 0.035 and CBH - R^2 0.0574) with a linear trendline (Figures 5.60 and 5.61) indicates that there is a very weak correlation between both CGL and CBH and age.

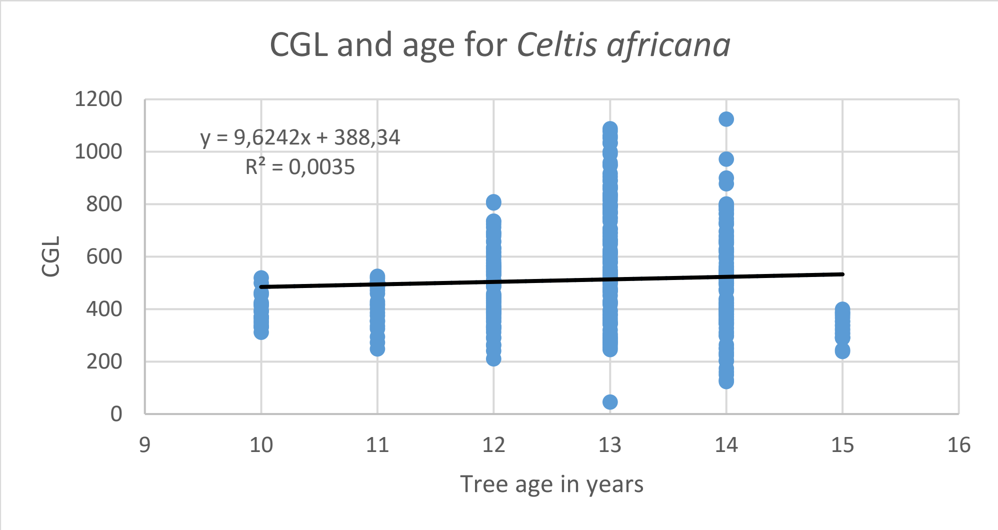


Figure 5.54: CGL and age for Celtis africana

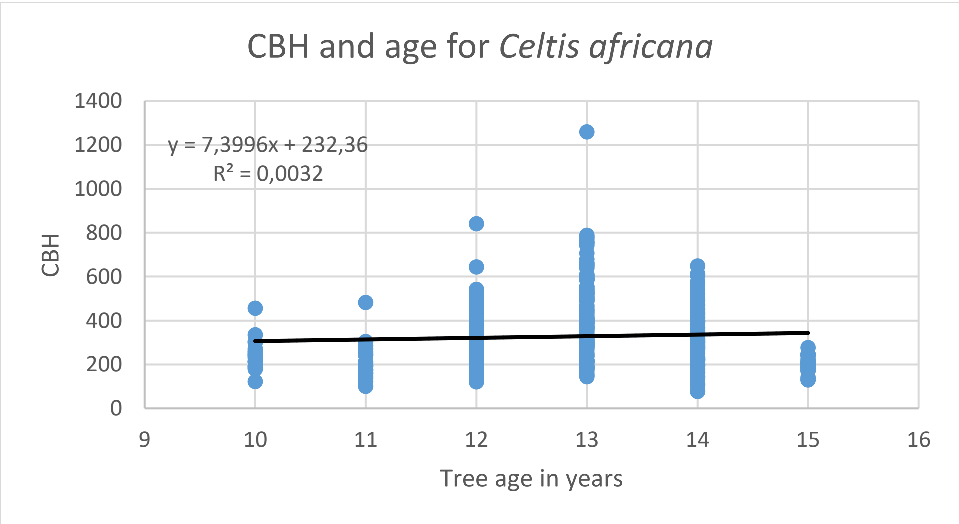


Figure 5.55: CBH and age for Celtis africana

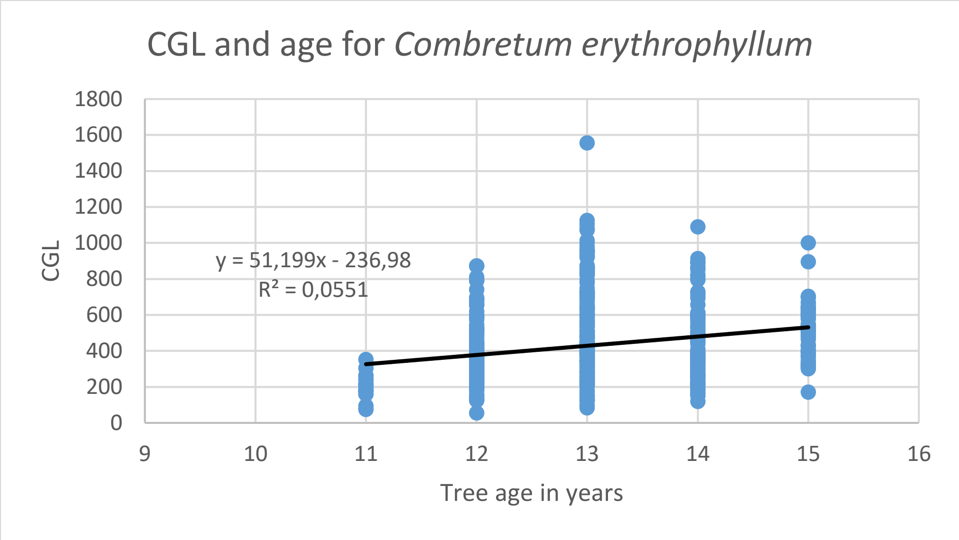


Figure 5.56: CGL and age for Combretum erythrophyllum

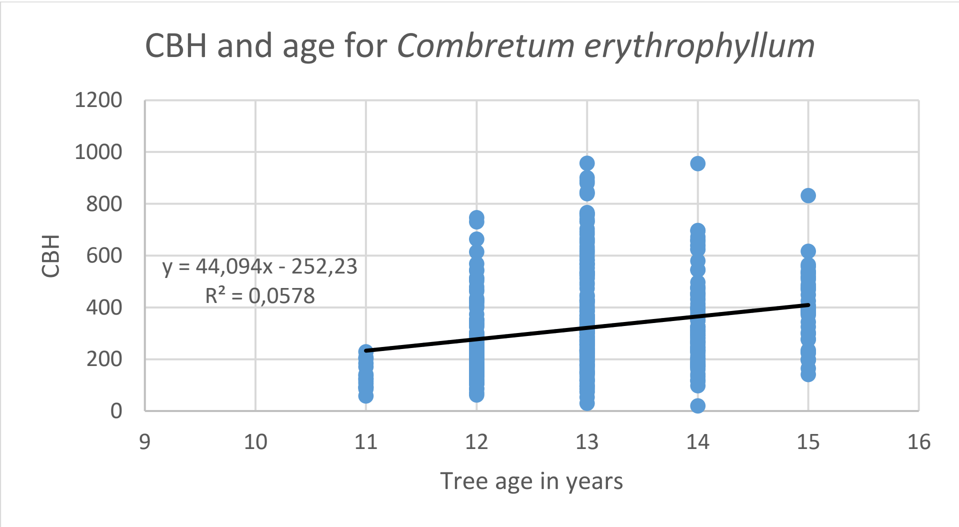


Figure 5.57: CBH and age for Combretum erythrophyllum

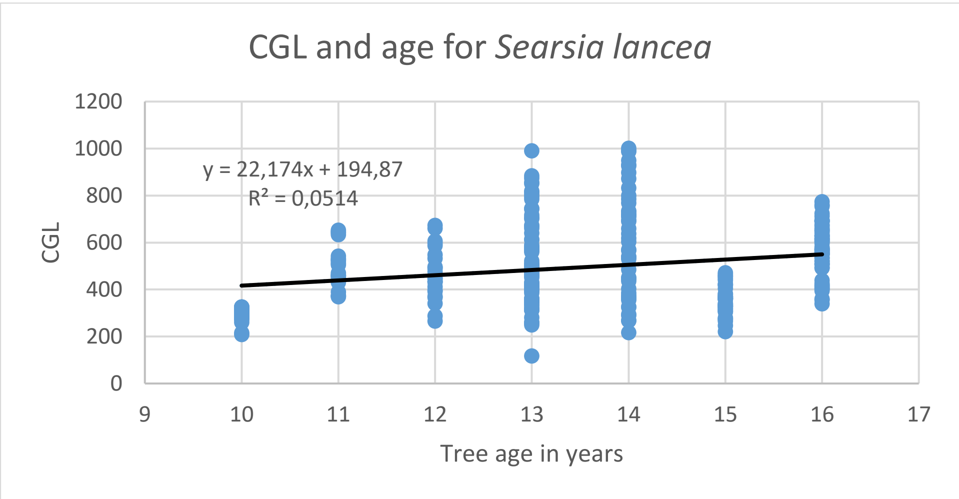


Figure 5.58: CGL and age for Searsia lancea

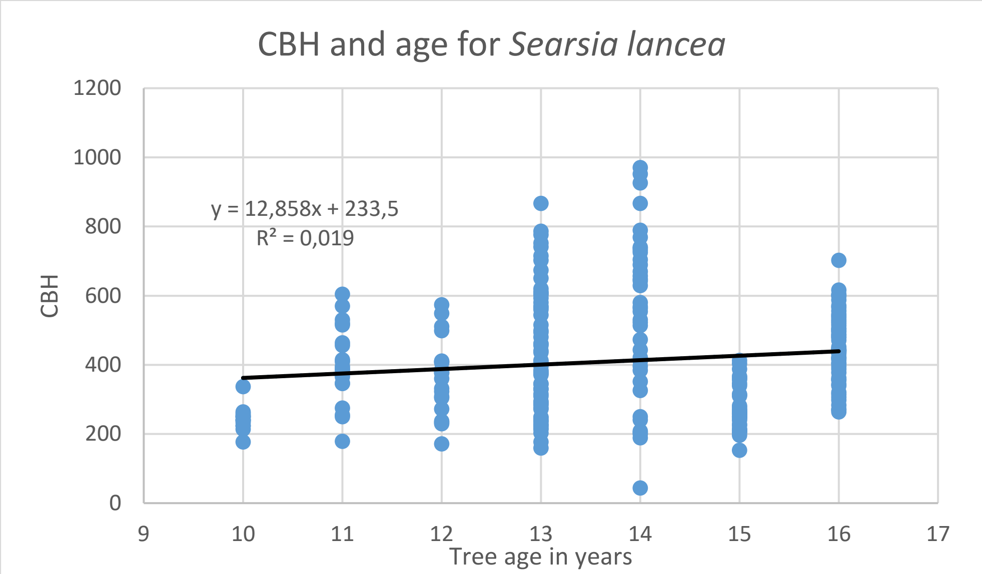


Figure 5.59: CBH and age for Searsia lancea

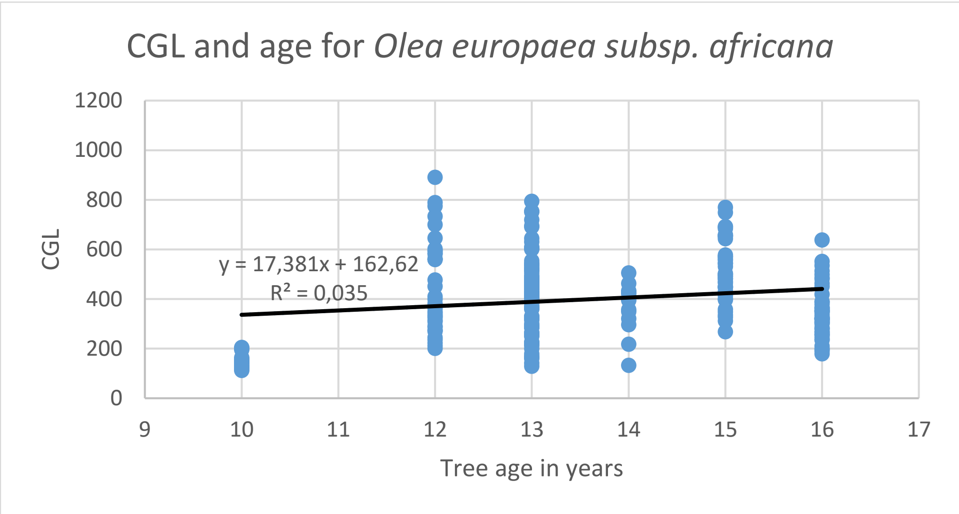


Figure 5.60: CGL and age for Olea europaea subsp. africana

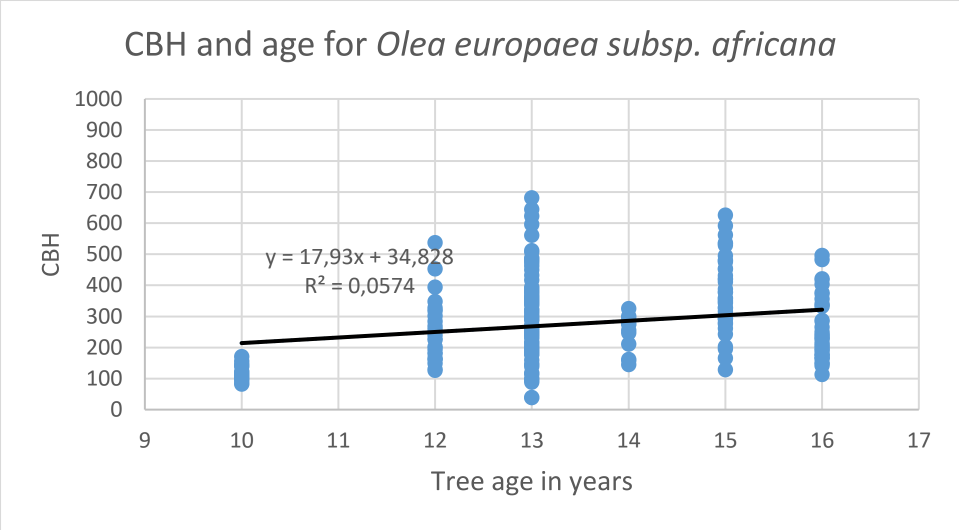


Figure 5.61: CBH and age for Olea europaea subsp. africana

5.4.9 Regression coefficients

The allometric equations used in international studies (Peper et al. 2001a, 2001b; Troxel et al., 2013; Semenzato et al., 2011; Stoffberg et al., 2008) reflect the effects of local site conditions and management practices on the growth of the trees, thereby limiting the application of these equations to similar areas or regions only (McPherson et al., 2016). In an attempt to develop new allometric equations for Gauteng, new constant values from this study were required to replace the constant values developed for the trees in the city of Tshwane and used in equations developed by Stoffberg (2006) and to come up with allometric equations for the CoJ.

Parameters to be predicted included the following: using tree age to predict CBH and CGL and the height of the maximum canopy diameter and using CBH and CGL to predict tree height. In analysing stem diameter growth, several growth curve models were tested (Stoffberg 2006): exponential (Zhang, 1997), first degree logistic (Brewer et al., 1985), Gompertz (Du Toit, 1979), Lundqvist (Brewer et al., 1985) and Richards family (Du Toit, 1979). The logarithmic equation (Peper et al., 2001a, 2001b) was used to determine the dimensional growth rates for the individual species in this study as it was considered to have the most appropriate fit. Tables 5.12 to 5.16 present the results for the growth parameters of *C. erythrophyllum*, *S. lancea*, *O. europaea* subsp. *africana* and *S. pendulina* trees using the equation of Peper et al. (2001a, 2001b).

$$\hat{y} = EXP\left(\frac{MSE}{2} + \left(A + b\log(\log(x_i + 1))\right)\right) \quad \text{(Eq 5.1)}$$

Where:

ŷ = Stem diameter to be estimated

Log = Natural logarithm of the argument

EXP = Inverse of the natural logarithm

MSE = Mean standard error

A and *b* = Parameters to be estimated

x_i = Age, stem circumferences or stem diameter

The results are provided as linear regressions with multiple variables (multivariate linear regression) and therefore the adjusted R-square is reported. Adjusted R-square calculates R-square from only those variables whose addition in the model is significant. The R-square reports on the degree of variation of the predicted variable, but will always increase irrespective of the variable significance.

Results for the growth parameters of *C. africana* are presented in Table 5.12. The stem circumferences for the Johannesburg data of *C. africana* (n = 358) ranged from 46 mm to 1 345 mm and the ages from 11 to 16 years. The adjusted R^2 values range from a very low R^{2} -0.001 for CBH and age to 0.124 for CBH and tree height, with very low R^2 values for CGL and age (R^2 = 0.001), crown height and age (R^2 = 0.105) and CGL and tree height (R^2 = 0.071). The significance (p-value) of the regressions is 0.000 ($p < 0.001$) for all CGL and tree height, CBH and tree height, and crown height and age. The significance of CBH and age and CGL and age is 0.278 and 0.464, respectively. This indicates that the regressions CGL and age, CGL and tree height, CBH and tree height, and crown height and age are statistically significant at an α-level of 0.05.

Table 5.12: Growth parameter regressions for Celtis africana

Celtis africana								
Growth parameters	n	A	b	MSE	Adjusted R^2	Lower con-fidence level	Upper con-fidence level	Significance
CGL and age	358	2.852E-11	0.058	0.083	0.001	0.001	0.001	0.278
CBH and age	358	1.329E-11	-0.039	0.096	-0.001	0.001	0.001	0.464
CGL and tree height	358	-0.157	-0.270	0.030	0.071	-0.215	-0.099	0.001
CBH and tree height	358	0.490	0.536	0.068	0.124	0.356	0.624	0.001
Crown height and age	358	-0.097	-0.329	0.015	0.105	-0.126	-0.068	0.001

n = sample size, (A, b) = estimated regression coefficients, MSE = mean standard error, R^2 = adjusted coefficients of determination

Results for the growth parameters of *C. erythrophyllum* are presented in Table 5.13. The stem circumferences of *C. erythrophyllum* (n = 543) ranged from 55 mm to 1 557 mm and the ages from 11 to 16 years. The adjusted R^2 values range from a very low R^2 0.001 for CGL and age and CBH and age to 0.242 for CBH and tree height, with low R^2 values for CGL and tree height (R^2 = 0.125) and crown height and age (R^2 = 0.144). The significance (p-value) of the regressions is 0.001 ($p < 0.001$)

for CGL and tree height, CBH and tree height, and crown height and age, but for CBH and CGL and age it is not significant. This indicates that the regressions CGL and tree height, CBH and tree height, and crown height and age are statistically significant at an α-level of 0.05.

Table 5.13: Growth parameter regressions for Combretum erythrophyllum

Combretum erythrophyllum								
Growth parameters	n	A	b	MSE	Adjusted R^2	Lower con-fidence level	Upper con-fidence level	Significance
CGL and age	543	3.837E-5	1.00	0.001	0.001	0.001	0.001	n.s
CBH and age	543	2.614E-8	1.00	0.001	0.001	0.001	0.001	n.s
CGL and tree height	543	-0.185	-0.356	0.021	0.125	-0.226	-0.144	0.001
CBH and tree height	543	0.367	0.493	0.028	0.242	0.312	0.421	0.001
Crown height and age	543	-0.111	-0.381	0.012	0.144	-0.134	-0.089	0.001

n = sample size, (A, b) = estimated regression coefficients, MSE = mean standard error, R^2 = adjusted coefficients of determination

Results for the growth parameters of *S. lancea* are presented in Table 5.14. The stem circumferences of *S. lancea* (n = 286) ranged from 44 mm to 1 104 mm and the ages from 11 to 16 years. The adjusted R^2 values range from a very low R^2 -0.002 for crown height and age to 0.167 for CGL and tree height, with low R^2 values for CGL and age ($R^2 = 0.001$), CBH and age ($R^2 = 0.035$) and CBH and tree height ($R^2 = 0.015$). The significance (p-value) of the regressions is 0.000 ($p < 0.001$) for CGL and tree height and 0.001 for CBH and age. The other regressions show significance at 0.021 (CBH and tree height), 0.299 (CGL and age) and 0.585 (crown height and age). This indicates that the regressions CGL and age, CGL and tree height, CBH and tree height, and crown height and age are statistically significant at an α-level of 0.05.

Table 5.14: Growth parameter regressions for Searsia lancea

Searsia lancea								
Growth parameters	n	A	b	MSE	Adjusted R^2	Lower con-fidence level	Upper con-fidence level	Significance
CGL and age	286	-1.385E-6	-0.061	0.001	0.000	0.001	0.001	0.299
CBH and age	286	-3.644E-6	-0.195	0.001	0.035	0.001	0.001	0.001
CGL and tree height	286	-0.125	-0.413	0.016	0.167	-0.157	-0.093	0.001
CBH and tree height	286	0.223	0.136	0.096	0.015	0.034	0.143	0.021
Crown height and age	286	-0.008	-0.032	0.015	-0.002	-0.037	-0.021	0.585

n = sample size, (A, b) = estimated regression coefficients, MSE = mean standard error, R^2 = adjusted coefficients of determination

Results for the growth parameters of *O. europaea* subsp. *africana* are presented in Table 5.15. The stem circumferences for *O. europaea* subsp. *africana* (n = 266) ranged from 39 mm to 682 mm and the ages from 11 to 16 years. The adjusted R^2 values range from a very low R^2 0.064 for CGL and tree height to 0.204 for CBH and tree height. CGL and age also had a low R^2 (0.099), for CBH and age ($R^2 = 0.066$) and crown height and age ($R^2 = 0.097$). The significance (p-value) of the regressions is 0.001 ($p < 0.001$) for all the regressions. This indicates that all the regressions are statistically significant at an α-level of 0.05.

Table 5.15: Growth parameter regressions for Olea europaea subsp. africana

Olea europaea subsp. africana								
Growth parameters	n	A	b	MSE	Adjusted R^2	Lower confide nce level	Upper confide nce level	Significance
CGL and age	266	7.966E-6	0.321	0.001	0.099	0.001	0.001	0.001
CBH and age	266	-2.062E-6	-0.263	0.001	0.066	0.001	0.001	0.001
CGL and tree height	266	-0.072	-0.260	0.016	0.064	-0.104	-0.040	0.001
CBH and tree height	266	0.460	0.455	0.055	0.204	0.351	0.569	0.001
Crown height and age	266	0.097	0.317	0.018	0.097	0.062	0.132	0.001

n = sample size, (A, b) = estimated regression coefficients, MSE = mean standard error, R^2 = adjusted coefficients of determination

Results for the growth parameters of *S. pendulina* are presented in Table 5.16. The stem circumferences for *S. pendulina* (n = 28) ranged from 60 mm to 1 145 mm and the ages from 11 to 16 years. The adjusted R^2 values range from a very low R^2 0.001 for both CGL and age and CBH and age to 0.179 for crown height and age, with low R^2 values for CBH and tree height ($R^2 = 0.038$) and CGL and tree height ($R^2 = 0.002$). The significance (p-value) of the regressions is 0.001 ($p < 0.001$) for CBH and age, 0.013 for crown height and age, 0.159 for CGL and tree height and 0.343 for CBH and tree height. The regression for CGL and age is not significant. This indicates that the regressions CBH and age, and crown height and age are statistically significant at an α-level of 0.05.

Table 5.16: Growth parameter regressions for Searsia pendulina

Searsia pendulina								
Growth parameters	n	A	b	MSE	Adjusted R^2	Lower con-fidence level	Upper con-fidence level	Significance
CGL and age	28	5.521E-5	1.000	0.001	0.001	0.001	0.001	n.s
CBH and age	28	4.885E-5	1.000	0.001	0.001	0.001	0.001	0.001
CGL and tree height	28	-0.158	-0.269	0.109	0.038	-0.383	0.066	0.159
CBH and tree height	28	-0.287	-0.183	0.297	0.002	-0.896	-0.323	0.343
Crown height and age	28	-0.122	-0.456	0.046	0.179	-0.215	-0.028	0.013

n = sample size, (A, b) = estimated regression coefficients, MSE = mean standard error, R^2 = adjusted coefficients of determination

5.4.10 Discussion: Growth relationship results

There is a strong relationship between CGL and CBH for all four species. The R^2 values are high (*C. africana* R^2 = 0.8884, *C. erythrophyllum* R^2 = 0.9058, *S. lancea* R^2 = 0.8154 and *O. europaea subsp. africana* R^2 = 0.8121), indicating that the fit in these linear relationships is very good and that CGL can be used to predict the CBH of the trees and that CBH can be used to predict CGL.

There are very weak to moderate correlations between both CGL, CBH and all the VolCalc growth parameters of all the trees. In all cases, the data points are spread in a dispersed manner in relation to the trendline. For the tree height and height of maximum canopy diameter parameters, the reason for the low R^2 value and the dispersed pattern may be the variation in the data and the substantial difference in the tree heights relative to the CGL and DBH of all the tree species across the study. The tallest *C. africana* tree was 7.62 m with a CGL of 779 mm and the shortest tree of the species was 1.62 m with a CGL of 224 mm. The tree with the widest CGL (1 125 mm) was 6.97 m tall and the tree with the smallest CGL (130 mm) was 3.26 m tall. A similar trend is found in most of the species. The tallest *C. erythrophyllum* tree was 7.68 m (CGL = 1 001 mm) and the shortest tree of the species was 1.12 m (75 mm). The tree with the widest CGL (1 551 mm) was 4.24 m tall. The tree with the smallest CGL was the shortest tree. The tallest *S. lancea* tree was 5.63 m (CGL = 930 mm) and the shortest tree of the species was 1.23 m (CGL = 565 mm). The tree with the widest CGL (991 mm) was 2.35 m tall and the tree with the smallest CGL (216 mm) was 1.75 m tall. The tallest *O. europaea subsp. africana* tree was 4.69 m (CGL = 452 mm) and the shortest tree of the species was 0.78 m (CGL = 427 mm). The tree with the widest CGL (789 mm) was 2.85 m tall and the tree with the smallest CGL (145 mm) was 1.69 m tall.

The reason for the dispersed pattern of the height at first leaf and the stem diameter at first leaf parameters relative to the CGL and DBH measurements is similar to the reason for the differences in height and CGL. However, the wide variety of heights at first leaf of all the tree species may be due to the observed lack of pruning across the sampled trees, where tree canopies were not pruned to a consistent height as can be expected with street trees, resulting in a low R^2 value. Similarly, the differences in maximum canopy diameter may be due to the variety of canopy shapes and sizes observed from the *C. africana, C. erythrophyllum* and *S. lancea* trees. The lack of structural pruning to shape tree canopies was evident. However, the results for *O. europaea* subsp. *africana* showed moderate correlations and higher R^2 values, which may be due to their natural compact crown shape. The reason for the dispersed pattern and low R^2 value of the volume parameter may be a combination of all the reasons provided for the other parameters above, as volume is calculated using all the parameters together. The tree height, canopy shape and size, stem diameter or circumference have a direct influence on the tree volume.

Very weak correlations with very low R-squares (0.03% and 5%) between both CGL and tree age, and CBH and tree age for all the trees in the study were identified. Low R-squares mean that there are other factors that have more influence on the CGL and CBH measurements than age. The other factors could be the influence of the environment, climate or soil, but more specifically, it is suggested that the planting specification, lack of maintenance and possible incorrectness of the data on the JCPZ inventory are contributing factors. The data points in the CGL/CBH and tree age graphs in this section display a vertical arrangement perpendicular to the trendline. This arrangement is consistent with international studies (Peper et al. 2001, 2001b; Semenzato et al., 2011) and the Stoffberg et al. (2008) study in Tshwane, South Africa. However, the results of this current study do not indicate the same rate of increase in the growth of the trees as their ages advance. In international studies, a clear progression in the growth (DBH/DGL measurements) of the trees relative to their ages is visible. The inconsistency of the current study's results with international DBH and age regression studies is confirmed by the low R^2 values of the results in this study. Peper et al. (2001a) presented R-squares between 0.85 and 0.91, Semento et al. (2011) presented R-squares between 0.76 and 0.907 and Troxel et al. (2013) presented R-squares between 0.562 and 0.725 for trees similar to *C. africana* and *C. erythrophyllum*. Stoffberg et al. (2009) presented R-squares of 0.76 for *C. erythrophyllum* and 0.84 for *S. lancea*.

The attempt to develop new allometric equations for the CoJ and Gauteng by creating new constant values for equations developed by Stoffberg (2006) was not successful. Even though the logarithmic equation (Peper et al., 2001a, 2001b) provided the most appropriate fit of all the equations attempted, R^2 values for all the growth relationships were very low, ranging from -0.001 to a maximum of 0.242, indicating that less than 25% of any of the growth relationships can be determined by any of the other growth relationships. The effort to establish dimensional growth rates for the individual species in this study was not positive and the development of growth rate equations for these trees could not be done.

5.5 Possibility of using the data to develop allometric equations

Most studies on urban tree allometry confirm that there should be a strong allometric relationship between growth parameters. Coombes, Martin and Slater (2019) affirm a strong allometric relationship between CBH and crown diameter of young to mature trees and Troxel et al. (2013) present strong allometric relationships for size dimensions (height and CBH, crown diameter and CBH, and crown volume and CBH) of urban trees in the north-eastern USA. Semenzato et al. (2011) found a strong relationship between growth parameters of large tree species and Peper et al. (2001a, 2001b) found strong relationships between growth parameters of a range of tree species. As mentioned before, Stoffberg et al. (2008) found strong relationships between the growth parameters of tree height, crown height, crown diameter and age for the trees in Tshwane, South Africa. The ages of these trees ranged from 1 to 7 years for all the trees and there was a wide gap in the tree ages to the oldest trees. *Combretum erythrophyllum* had no data between 7 and 45.5 years, *S. lancea* had no data between 7 and 30.5 years, *O. europaea subsp. africana* had no data between 7 and 40.5 years and *S. pendulina* had no data between 7 and 15 years.

In an attempt to find a way to use the data from this study to develop new growth equations for these trees, additional actions were taken. The data from this study was combined with the raw data from the Tshwane study by Stoffberg (2006) to investigate if the addition of data could improve the growth relationships, enabling growth equations to be developed for Gauteng. As described above, the Tshwane study did not have data for the same years as the data from this study, and combining the data provided data in the ages where there was no data. Likewise, an improvement of the Tshwane R-squares was aimed for in combining the data. Subsequently, different growth equations presented in McPherson et al. (2016) were used to determine if there were equations that could improve the relationships and provide a more appropriate fit to the data. Finally, due to the inconsistency of the results with international DBH and age regression studies and the importance of age as the first step in determining allometric equations, the "Tree age and correlated sequestrated carbon, stem circumference and stem diameter predictive table" provided by Stoffberg (2006) was applied to the stem diameter of the trees to ascertain if the ages of the trees of this study were correct. The new ages were used to establish if a more appropriate fit of the data could be established. The results for the additional actions are presented and discussed below.

5.5.1 Growth relationships (CGL and age) using combination of data from current study and Tshwane study

The Tshwane study results present data for *C. erythrophyllum*, *S. lancea* and *S. pendulina*. It did not produce growth relationships for *C. africana* (species did not form part of the study) and only provided raw data for *O. europaea subsp. africana*. Therefore, results are presented for a combination of *C. erythrophyll*um, *S. lancea, O. europaea subsp. africana* and *S. pendulina* data from this study and the Tshwane study. Combined results are provided for CGL and age to determine if there is any improvement in the R-squares of the data analysis. In each case all the trendlines were applied and only the best fitting trendline was applied to the graphs. For this part of the study results are presented for CGL and age only, as there is a strong correlation between CGL and age of this study, as presented and described in section 5.4.1.

The growth relationships (CGL and age) for *C. erythrophyllum* using a combination of the data from this study (referred to as Johannesburg data) and the raw data from the Tshwane study (referred to as Tshwane data) are presented in Figure 5.62. The data from both cities is visible on one graph. The logarithmic trendline is the best fitting trendline for the Tshwane data with an R^2 value of 0.7702 and the Johannesburg data has a linear trendline with an R^2 value of 0.0728. The difference in the R^2 value is noticeable.

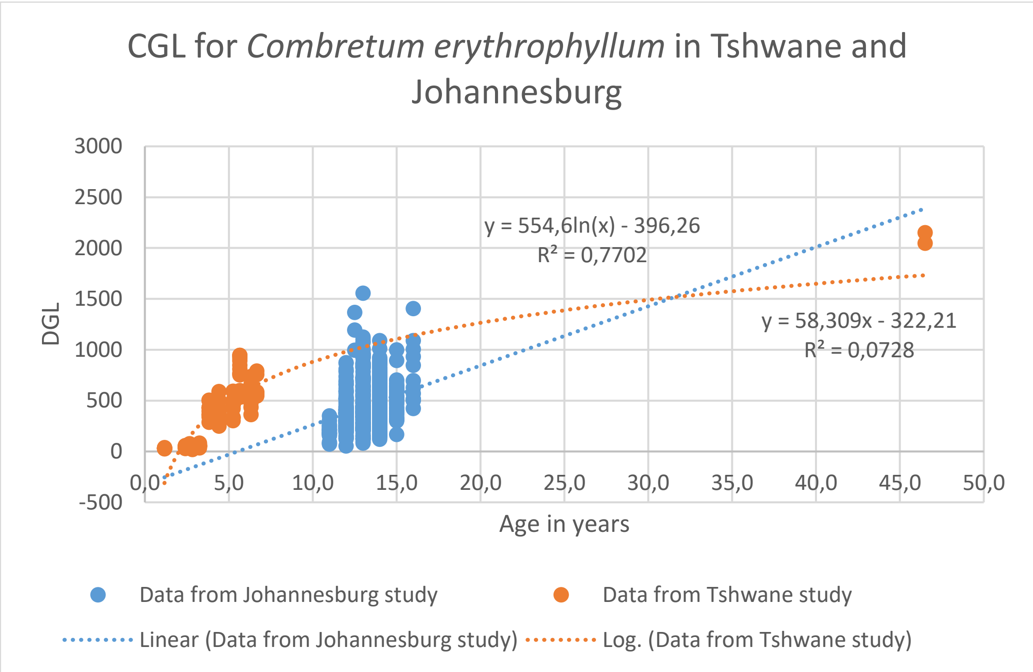


Figure 5.62: CGL and age results for both cities for Combretum erythrophyllum

When the data (CGL and age) of the two studies is combined (Figure 5.63), the R^2 value of the Johannesburg study improves to 0.1702 with a linear trendline and to 0.3637 with a power trendline as the best fit. However, the combination of the data reduces the high R^2 value of the Tshwane study from 0.7702 to 0.3637. The power trendline in Figure 5.63 is presented by a red dotted line.

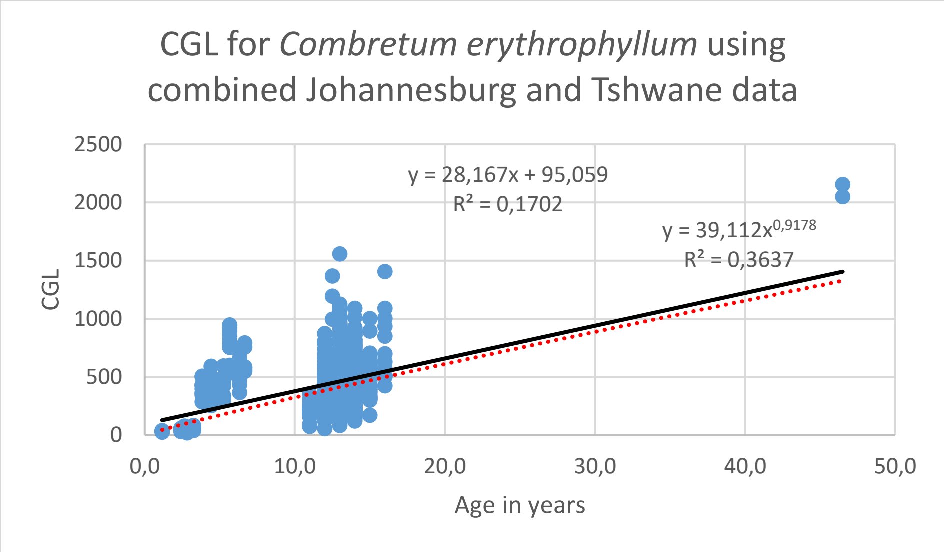


Figure 5.63: Combined results for CGL and age for Combretum erythrophyllum

The growth relationships (CGL and age) for *S. lancea* using a combination of the Johannesburg data and the Tshwane data are presented in Figure 5.64. The data from both cities is visible on one graph. The Tshwane data has a linear trendline as the best fit and an R^2 value of 0.8898 and the Johannesburg data has a power trendline as a best fit with an R^2 value of 0.1009. The difference in the R^2 value is distinct.

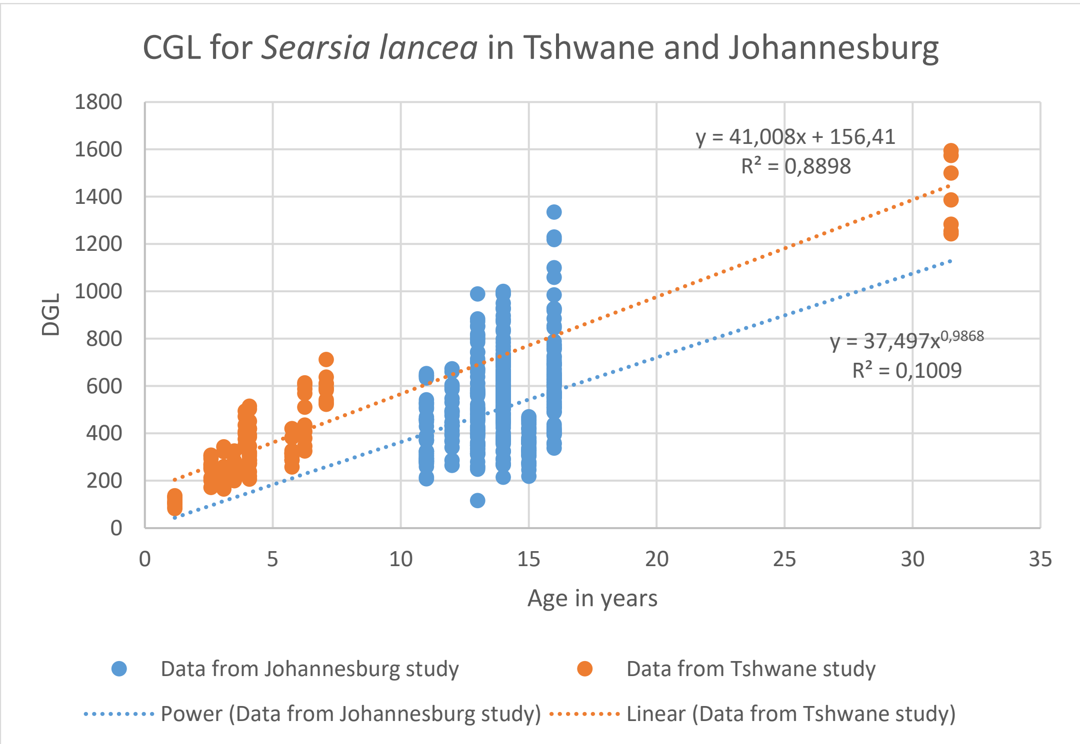


Figure 5.64: CGL and age results for both cities for Searsia lancea

When the data (CGL and age) of the two studies is combined (Figure 5.65), the R^2 value of the Johannesburg study with a linear trendline improves to 0.3967 and to 0.4377 with a best fitting power trendline. However, the combination of the data reduces the high R^2 value of the Tshwane study from 0.8898 to 0.4377. The power trendline is presented on the graph in a red dotted line.

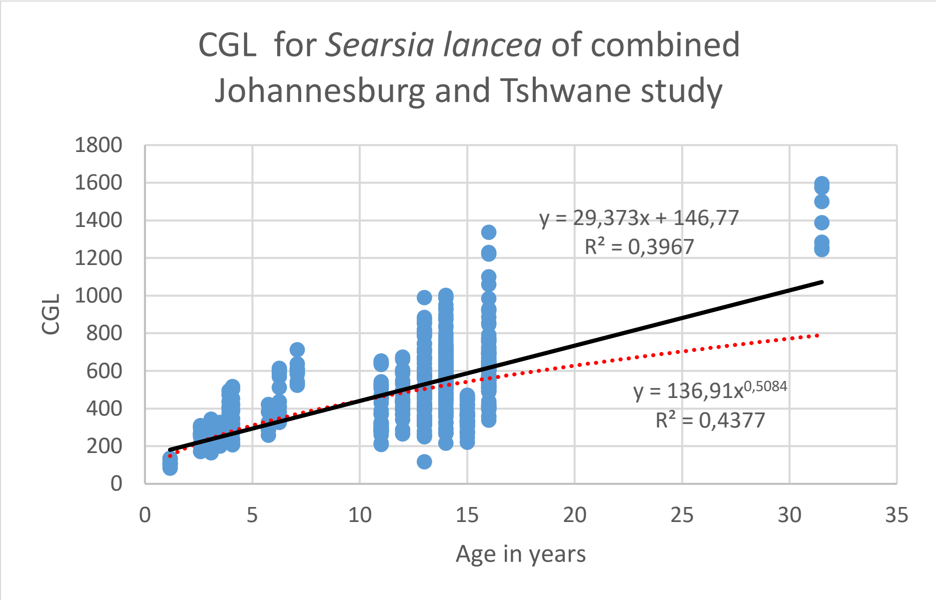


Figure 5.65: Combined results for CGL and age for Searsia lancea

The growth relationships (CGL and age) for *O. europaea* subsp. *africana* using a combination of the Johannesburg data and the Tshwane data are presented in Figure 5.66. The Tshwane data has a linear trendline as the best fit and an R^2 value of 0.9337 and the Johannesburg data has a power trendline as the best fit with an R^2 value of 0.0209. The difference in the R^2 value is very clear.

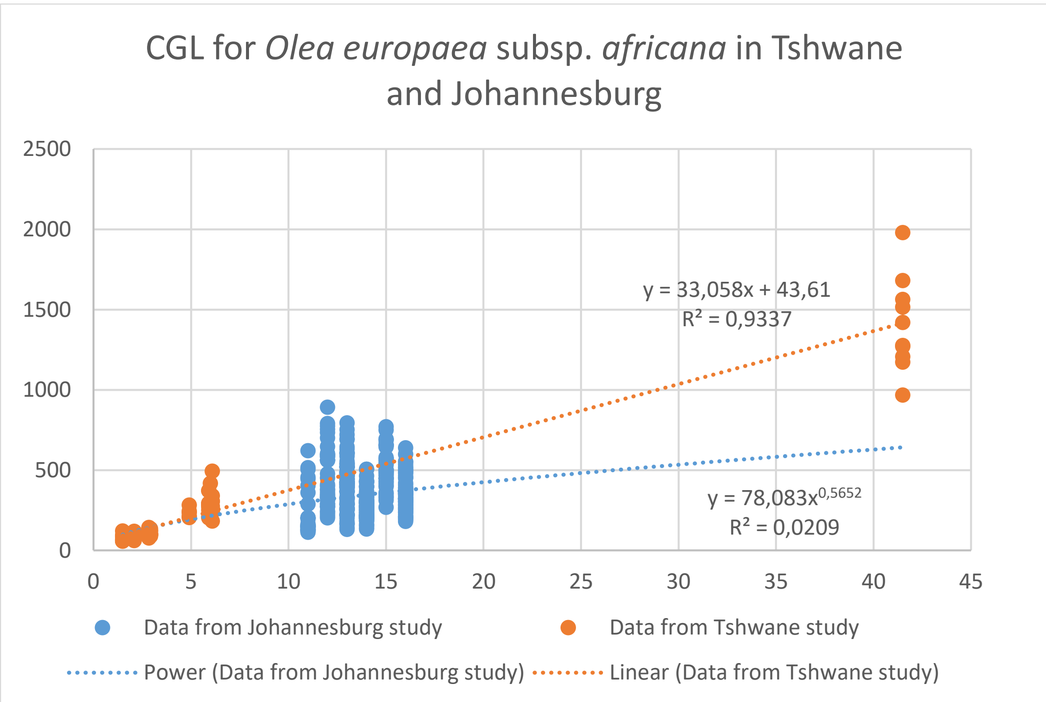


Figure 5.66: CGL and age results for both cities for Olea europaea subsp. africana

When the data (CGL and age) of the two studies is combined (Figure 5.67), the R^2 value of the Johannesburg study with a best fitting linear trendline improves to 0.5469. The combination of the data does reduce the high R^2 value of the Tshwane study from 0.9338 to 0.5469. However, the R^2 of 0.5469 is acceptable and the best R-square that was found for the combined data of all the species. Compared to the linear trendline, none of the other trendlines provided a better fit.

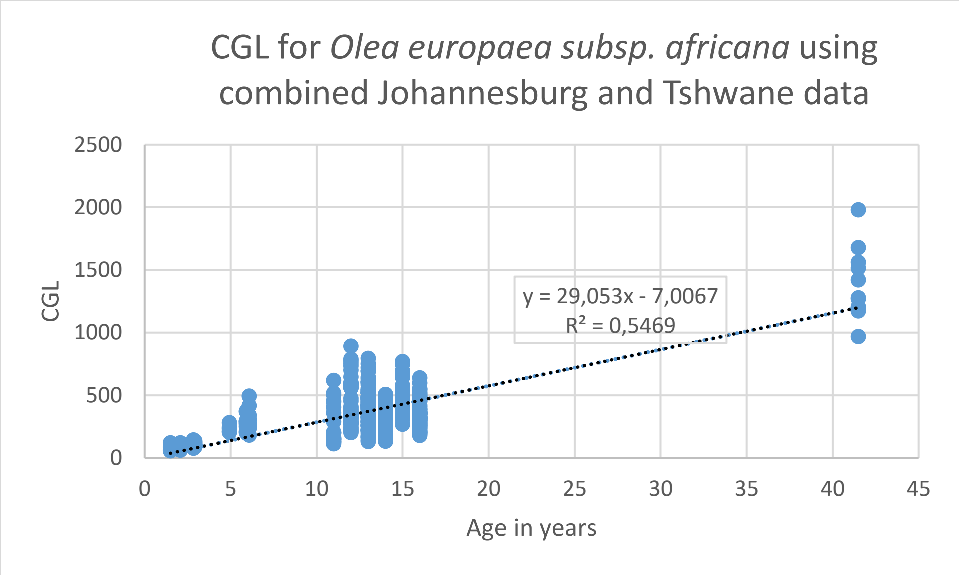


Figure 5.67: Combined results for CGL and age for Olea europaea subsp. africana

The growth relationships (CGL and age) for *S. pendulina* using a combination of the Johannesburg data and the Tshwane data are presented in Figure 5.68. The Tshwane data has a linear trendline as the best fit and an R^2 value of 0.836 and the Johannesburg data has a power trendline with an R^2 value of 0.0672. The difference in the R^2 value is apparent.

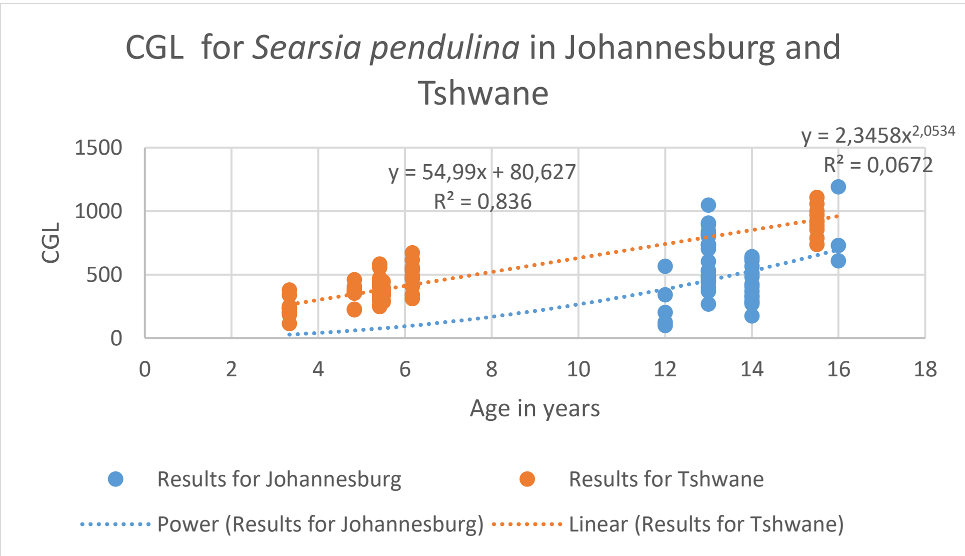


Figure 5.68: CGL and age results for both cities for Searsia pendulina

When the data (CGL and age) of the two studies is combined (Figure 5.69), the R^2 value of the Johannesburg study with a linear trendline improves to 0.3735, but the combination of the data reduces the high R^2 value of the Tshwane study from 0.836 to 0.3735. Compared to the linear trendline, none of the other trendlines provided a better fit.

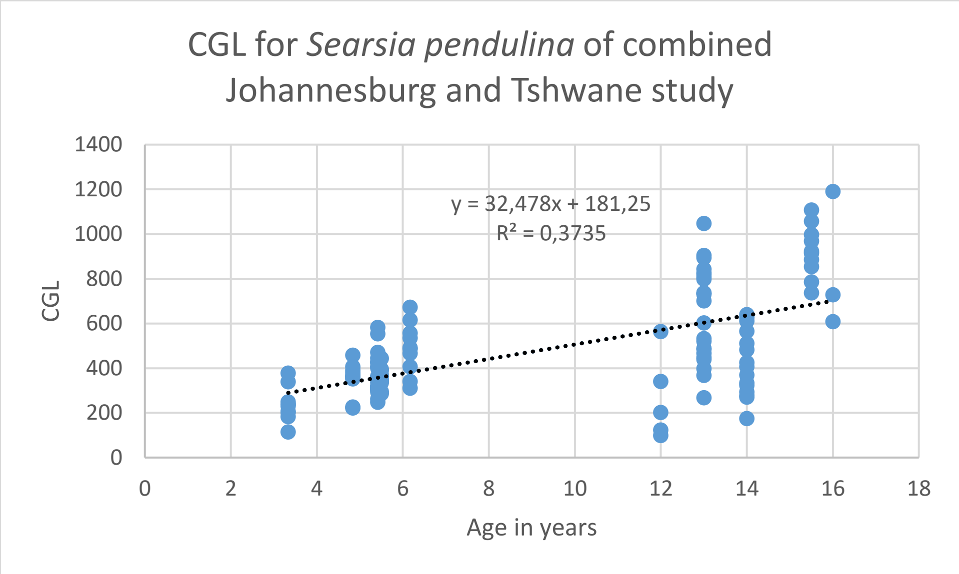


Figure 5.69: Combined results for CGL and age for Searsia pendulina

Therefore, when the data from the Johannesburg study is combined with the data from the Tshwane study for *C. erythrophyll*um, *S. lancea, O. europaea* subsp. *africana* and *S. pendulina*, there is an improvement in the R-squares of the Johannesburg data. However, the combination of the data reduces the high R^2 values of the Tshwane data. The improvement of the Johannesburg R-squares may be attributed to the wider range of data. The range of age of the Johannesburg dataset increased from 6 years to between 16 and 45 years (depending on the species) with many smaller and larger trees in the dataset. The decrease in the Tshwane R-squares may be attributed to the large portion of Johannesburg data consolidated in a short period (six years) when added to the Tshwane data. The Tshwane data consisted of 105 *C. erythrophyllum* trees*,* 107 *S. lancea* trees and 95 *O. europaea* subsp. *africana* trees, whereas the Johannesburg data consisted of 543 *C. erythrophyllum* trees, 286 *S. lancea* trees and 266 *O. europaea* subsp. *africana* trees.

In summary, the new R-squares for *C. erythrophyll*um, *S. lancea, O. europaea* subsp. *africana* and *S. pendulina* were improved from the Johannesburg R-squares to 0.2778, 0.4104, 0.5469 and 0.3735, respectively. International studies by Peper et al. (2001a, 2001b) have produced R^2 values of above 40% for similar tree species and therefore it could be possible to develop growth equations for *S. lancea* (R^2 = 0.4104) *and O. europaea* subsp. *africana* (R^2 = 0.5469), using the combined data from both studies. The R-square for *C. erythrophyll*um (R^2 = 0.2778) remained very low and therefore new growth equations were not developed. An alternative interpretation of the results could be that separate allometric equations for each city is required and that data from more than one city should not be added to another city's dataset.

5.5.2 Regression coefficients for the combined data

Due to the low R^2 values of the regression coefficients of the trees of this study, seen in Tables 5.12 to 5.16 of this chapter, for the Johannesburg data on its own, an attempt was made to develop new constants by combining the data from the Tshwane and Johannesburg studies using the logarithmic equation (Peper et al., 2001a, 2001b) as it was considered to provide the most appropriate fit. These equations can be used to calculate the quantity of carbon sequestered over a period for *C. erythrophyll*um, *S. lancea* and *S. pendulina* trees. Results are presented for allometric equations for *C. erythrophyll*um, *S. lancea*, *O. europaea* subsp. *africana* and *S. pendulina* using the combined data. The aim was to increase the data pool variables and create new equations for Gauteng by using the Tshwane and Johannesburg data together.

Results are presented for the growth parameters (CGL and age, CBH and age, CGL and tree height, CBH and tree height, and crown height and age) with the best results for the tree species mentioned above. This part of the study was not conducted for *C. africana* as the Tshwane study did not provide data for this species.

Results for the combined data for the growth parameters of *C. erythrophyllum* are presented in Table 5.17. The stem circumferences for the combined Johannesburg and Tshwane data of *C. erythrophyllum* (n = 648) ranged from 20 mm to 2 154 mm, whereas the stem circumferences for the Johannesburg data (n = 543) on its own ranged from 55 mm to 1 557 mm. The ages ranged from 1 year and 2 months to 46.5 years. The adjusted R^2 values ranged from a very low -0.001 for CGL and age to 0.390 for CBH and age, with low R^2 values for CGL and tree height (0.106), crown height and age (0.159) and CBH and tree height (0.273). The significance (p-value) of the regression is 0.657 for CGL and age and 0.000 ($p < 0.001$) for all the other regressions. The negative (-) coefficients indicate that as the dependent variable (age) increases, the independent variable (CGL) decreases. This indicates that the regressions for CGL and age are not statistically significant and the regressions for CBH and age, CGL and tree height, CBH and tree height, and crown height and age are statistically significant at an α-level of 0.05.

Table 5.17: Growth parameter regressions for Combretum erythrophyllum *using combined data*

Combretum erythrophyllum								
Growth parameters	n	A	b	MSE	Adjusted R^2	Lower confidence level	Upper confidence level	Significance
CGL and age	648	-95.133	-0.017	213.84	-0.001	-515.033	324.767	0.657
CBH and age	648	-0.403	-0.625	0.020	0.390	-0.442	-0.364	0.001
CGL and tree height	648	-0.185	-0.327	0.021	0.106	-0.227	-0.144	0.001
CBH and tree height	648	0.388	0.524	0.025	0.273	0.339	0.436	0.001
Crown height and age	648	-0.134	-0.400	0.012	0.159	-0.158	-0.110	0.001

n = sample size, (A, b) = estimated regression coefficients, MSE = mean standard error, R^2 = adjusted coefficients of determination

Results for the combined data for the growth parameters of *S. lancea* are presented in Table 5.18. The stem circumferences for the combined Johannesburg and Tshwane data of *S. lancea* (n = 361) ranged from 83 mm to 1 595 mm, whereas the stem circumferences for the Johannesburg data (n = 286) on its own ranged from 117 mm to 1 336 mm. The ages ranged from 1 year and 2 months to 31.5 years. The adjusted R^2 values ranged from a very low -0.002 for crown height and age to 0.550 for CBH and age and the significance (p-value) of the regression ranged from 0.358 for crown height and age to 0.000 ($p < 0.001$) for CGL and age, CBH and age, and tree height and age. The R^2 values of the other regressions are low at 0.044, 0.024 and 0.216 for CBH and age, CGL and tree height, and CBH and tree height, respectively. This indicates that the regressions for crown height and age are not statistically significant and the regressions for CGL and age, CBH and age, CGL and tree height, and CBH and tree height are statistically significant at an α-level of 0.05.

Table 5.18: Growth parameter regressions for Searsia lancea *using combined data*

Searsia lancea								
Growth parameters	n	A	b	MSE	Adjusted R^2	Lower confidence level	Upper confidence level	Significance
CGL and age	393	0.371	0.742	0.017	0.550	0.338	0.404	0.001
CBH and age	393	1149.64	0.473	217.182	0.216	718.595	1580.68	0.001
CGL and tree height	393	-.073	-0.163	0.022	0.024	-0.117	-0.029	0.001
CBH and tree height	393	-462	-0.215	0.106	0.044	-0.670	-0.254	0.001
Crown height and age	393	-0.065	-0.122	-0.070	-0.002	-0.206	0.076	0.358

n = sample size, (A, b) = estimated regression coefficients, MSE = mean standard error, R^2 = adjusted coefficients of determination

Results for the combined data for the growth parameters of *O. europaea* subsp. *africana* are presented in Table 5.19. The stem circumferences for the combined Johannesburg and Tshwane data of *O. europaea* subsp. *africana* (n = 361) ranged from 56 mm to 1 980 mm, whereas the stem circumferences for the Johannesburg data (n = 266) on its own ranged only from 113 mm to 891 mm. The ages of the trees ranged from 1 year and 6 months to 41.5 years. The adjusted R^2 values ranged from 0.917 for CGL and age and 0.959 for CBH and age to 0.086 for CGL and age. The R-squares of the other regressions are low at 0.181 and 0.311 for CGL and tree height, and crown height and age, respectively. The significance (p-value) of all the regressions is 0.000 ($p < 0.001$), indicating that the regressions are statistically significant at an α-level of 0.05.

Table 5.19: Growth parameter regressions for Olea europaea subsp. africana *using combined data*

Olea europaea subsp. *africana*								
Growth parameters	n	A	b	MSE	Adjusted R^2	Lower confidence level	Upper confidence level	Significance
CGL and age	361	0.302	0.979	0.003	0.959	0.296	0.309	0.001
CBH and age	361	0.626	0.958	0.010	0.917	0.606	0.645	0.001
CGL and tree height	361	-0.098	-0.297	0.017	0.086	-0.130	-0.065	0.001
CBH and tree height	361	0.559	0.559	0.044	0.311	0.473	0.645	0.001
Crown height and age	361	0.148	0.428	0.017	0.181	0.115	0.181	0.001

n = sample size, (A, b) = estimated regression coefficients, MSE = mean standard error, R^2 = adjusted coefficients of determination

Results for the combined data for the growth parameters of *S. pendulina* are presented in Table 5.20. The stem circumferences for the combined Johannesburg and Tshwane data of *S. pendulina* (n = 98) ranged from 99 mm to 1 191 mm, whereas the stem circumferences for the Tshwane data (n = 70) on its own ranged from 114 mm to 1 107 mm. The ages of the trees ranged from 3 to 16 years. The adjusted R^2 values ranged from 0.002 for crown height and age to 0.543 for CGL and age and the significance (p-value) of the regression ranged from 0.358 for crown height and age to 0.001 ($p < 0.001$) for CGL and age, and CBH and age. This indicates that the regressions for crown height and age, CGL and tree height, and CBH and tree height are not statistically significant and the regressions for CGL and age, and CBH and age are statistically significant at an α-level of 0.05.

Table 5.20: Growth parameter regressions for Searsia pendulina *using combined data*

Searsia pendulina								
Growth parameters	n	A	b	MSE	Adjusted R^2	Lower confidence level	Upper confidence level	Significance
CGL and age	98	-21415.37	-0.740	1976.345	0.543	-25337.872	-17492.875	0.001
CBH and age	98	1149.640	0.478	217.182	0.216	718.595	1580.686	0.001
CGL and tree height	98	-0.156	-0.185	0.084	0.024	-0.324	0.011	0.067
CBH and tree height	98	0.150	0.143	0.105	0.010	-0.058	0.357	0.157
Crown height and age	98	0.065	-0.122	0.070	0.002	-0.206	0.076	0.358

n = sample size, (A, b) = estimated regression coefficients, MSE = mean standard error, R^2 = adjusted coefficients of determination

In summary, the results for the development of new constant values for growth parameters by combining data from the Johannesburg and Tshwane studies using the logarithmic equation provided improved results compared to the results in section 5.4.9 (Johannesburg study data) of this chapter. The results for CGL and age improved for *S. lancea* to R^2 = 0.550, for *O. europaea* subsp. *africana* to R^2 = 0.959 and for *S. pendulina* to R^2 = 0.543. The results for CBH and age improved for *C. erythrophyllum* to R^2 = 0.390, *S. lancea* to R^2 = 0.216, for *O. europaea* subsp. *africana* to R^2 = 0.917 and for *S. pendulina* to R^2 = 0.216. The results for the other growth relationships (CGL and tree height, CBH and tree height, and crown height and age) improved but remained very low. For *C. erythrophyllum* the R-squares remained between 0.106 and 0.273, for *S. lancea* they remained between -0.002 and 0.044, for *O. europaea* subsp. *africana* they remained between 0.086 and 0.311 and for *S. pendulina* they remained between 0.002 and 0.024.

The significant results for CGL and age and CBH and age, with moderate to strong R-squares, are presented in Table 5.21. The relationships between CGL and age for *S. pendulina* (R^2 = 0.543), *S. lancea* (R^2 = 0.550) and *O. europaea* subsp. *africana* (R^2 = 0.959) were significant, as was the relationship between CBH and age for *O. europaea* subsp. *africana* (R^2 = 0.917). These relationships produced the best coefficients of determination (R-squares) and the constant values (*A, b* and MSE) from these relationships and were subsequently tested to identify whether they could be used to determine new growth estimations for these species. The relationships between CBH and age for *S. lancea* and *S. pendulina* were not significant.

Table 5.21: CGL vs age and CBH vs age of Searsia lancea, Olea europaea subsp. africana *and* Searsia pendulina *for combined data using logarithmic equation*

Species	CGL and age					CBH and age				
	n	***A***	**b**	**MSE**	**R^2**	***n***	***A***	**b**	**MSE**	**R^2**
Searsia lancea	393	0.371	0.742	0.017	0.550	393	1149.640	0.473	217.182	0.216
Olea europaea subsp. africana	361	0.302	0.979	0.003	0.959	361	0.626	0.958	0.010	0.917
Searsia pendulina	98	-21415.374	-0.740	1976.345	0.543	98	1149.640	0.478	217.182	0.216

n = sample size, (A, b) = estimated regression coefficients, MSE = mean standard error, R^2 = adjusted coefficients of determination

These regression coefficients were applied to (Eq.1) C_i = EXP(MSE/2+($\hat{A}$+*b*(ln(ln(x+1))))) to determine if these new constant values can be used to estimate circumference as the starting point to predict growth.

The calculations using the *S. pendulina* values did not produce a result. Therefore, new growth equations were not developed for this species. The calculations using the *O. europaea* subsp. *africana* and *S. lancea* values produced results. Therefore, these new constant values can be used to estimate circumference for these tree species in Gauteng, South Africa.

5.5.3 Adapting allometric equations provided by McPherson et al. (2016) to combined data

The equations presented up to now in this thesis were logarithmic regression and exponential models used by Peper et al. (2001a, 2001b) and Stoffberg et al. (2008) to determine growth equations for specific tree species in the cities of Santa Monica and Modesto, California, USA, and the City of Tshwane, South Africa. The “Urban tree database and allometric equations” report by McPherson et al. (2016) presents an updated list of growth equations using more sophisticated statistical methods to provide growth equations that best fit measured data ranging from linear to quadratic trendlines and logarithmic and exponential models (Peper et al., 2014). In attempting to develop growth equations for the trees from this study, it was decided to apply the new growth equations from the McPherson et al. (2016) report and determine whether this could be the solution to the low R-squares discussed above.

Peper et al. (2014) tested six models for seven parameters, which included using tree age to predict DBH, and using DBH to predict tree height, crown height, crown diameter and leaf area. These models provided the equations which were applied to the trees from this study and are described in the method chapter. The equations for each tree species from this current study were identified using the same or species similar in growth form and habit, and region in the USA, with a climate (temperature, precipitation and height above sealevel) similar to that of the CoJ in Gauteng, South Africa (Table 5.22). The measurements used by Peper et al. (2014) were for diameter and therefore for this part of the study, the circumference measurements were converted to diameter. These equations provided the coefficients to use in each model, the minimum and maximum values to estimate between, mean square error, sample size, adjusted R^2, the raw data range and the degrees of freedom. In all instances age was used to predict DBH and DBH was used to predict or calculate tree height, crown height, crown diameter and leaf area. Results are presented for the combined data from the Johannesburg and Tshwane studies.

Table 5.22: Best fitting allometric equation models from McPherson et al. (2016)

Tree species	Similar tree species (McPherson et al., 2016)	Region in the USA	Variables	Equation name linked to the model
Celtis africana	*Celtis sinensis*	Inland valleys	DBH from age	quadratic
			Tree height	loglogw4
			Crown height	loglogw4
			Crown diameter	loglogw4
			Leaf area	loglogw4
Combretum erythrophyllum	*Jacaranda mimosifolia*	Southern California coast	DBH from age	linear
			Tree height	linear
			Crown height	linear
			Crown diameter	quadratic
			Leaf area	loglogw1
Searsia lancea	*Searsia lancea*	South-west desert	DBH from age	linear
			Tree height	linear
			Crown height	linear
			Crown diameter	quadratic
			Leaf area	loglogw1
Olea europaea subsp. africana	*Olea europaea*	South-west desert	DBH from age	Quadratic
			Tree height	loglogw1
			Crown height	loglogw1
			Crown diameter	Loglogw3
			Leaf area	loglogw1
Searsia pendulina	*Schinus terebinthifolia*	Southern California coast	DBH from age	quadratic
			Tree height	loglogw1
			Crown height	loglogw2
			Crown diameter	loglogw2
			Leaf area	loglogw1

Models listed per equation name for the variables in this study for Celtis africana, Combretum erythrophyllum, Searsia lancea, Olea europaea subsp. africana *and* Searsia pendulina, *also indicating the supplemented species where the South African species were not included in the report and the region in the USA with a climate similar to that of the CoJ*

5.5.3.1 Results for new allometric equations to predict DBH from age

The combined data in Table 5.23 illustrates the results of the ages and predicted DBH measurements for the two studies using the equations (DBH from age) for each species, as seen in Table 5.22. Results for *C. africana* are included but these results are for the Johannesburg study on its own. The tree ages of most of the trees of the Tshwane study (in red) indicate that young trees ranging from 1 to 7 years and older trees between 32 and 46 years formed part of the study and the trees in the Johannesburg study (in black) ranged from 11 to 16 years.

Applying the new allometric equations seen in Table 5.22 to the data of *C. africana* to predict DBH using age produced DBH predictions that were higher than the measured DBH in each of the years of the study. Applying the new allometric equations to the combined data of the *C. erythrophyllum, S. lancea, O. europaea subsp. africana* and *S. pendulina* trees produced conflicting results for the Tshwane study, but the predicted DBH measurements for these trees across all the ages in the Johannesburg study produced larger DBH measurements than the actual measurements. The trees from the Johannesburg study had much smaller mean DBH measurements than the predicted DBH measurements. The predicted DBH measurement for the oldest *C. erythrophyllum* trees (46 years) was distinctly smaller than the actual measurement, and the predicted measurement of the youngest trees (1 and 3 years) was notably larger than the actual trees measured. In contrast, years 4 to 7 of the Tshwane study produced higher mean DBH measurements than the predicted measurements. The DBH measurements for *S. lancea* produced similar results to those of *C. erythrophyllum* in the Tshwane study where most of the predicted measurements were smaller than the DBH measurements, except for the youngest trees (1 and 3 years) where larger predicted measurements were produced. In contrast, the predicted measurements for *O. europaea* subsp*. africana* and *S. pendulina* were larger than the mean measurements across all ages, except for the measurements of year 3 of *O. europaea subsp. africana* and year 15 of *S. pendulina*, where the mean measurements of the trees in that year were larger than predicted.

As the predicted DBH measurements are directly linked to age in the new equations, a steady increase in these predicted DBH measurements is clearly visible in Table 5.23. The mean DBH measurements of the trees in the Tshwane study also increase as the years increase. However, the mean DBH measurements of the trees in the Johannesburg study do not follow the same pattern and do not necessarily increase with age. The only species where the DBH measurements increased with age was *C. erythrophyllum.* The measurements of *C. africana* trees were the largest for the trees in year 13, followed by year 16, and the measurements for the trees in year 15 were smaller than the measurements of the youngest trees in year 11. The actual measurements of *S. lancea* trees were the largest for the trees in year 16, followed by years 14 and 12, and the smallest measurements were the trees in year 11, but the second smallest tree measurements were in year 15. The measurements of *O. europaea* subsp*. africana* trees were the smallest in year 16 and were also smaller than the measurements of years 14, 13 and 12. The measurements of the second largest *S. pendulina* trees were from year 13 and the second smallest were from year 14.

Table 5.23: Tree age with corresponding predicted DBH measurements and mean of actual DBH measurements of combined studies

Tree age in years	*Celtis africana*		*Combretum erythrophyllum*		*Searsia lancea*		*Olea europaea subsp. africana*		*Searsia pendulina*	
	Predicted DBH in cm using "quad" equation	Mean DBH in cm	Predicted DBH in cm using "lin" equation	Mean DBH in cm	Predicted DBH in cm using "lin" equation	Mean DBH in cm	Predicted DBH in cm using "quad" equation	Mean DBH in cm	Predicted DBH in cm using "quad" equation	Mean DBH in cm
46			38.64	64.96						
42							49.82	45.05		
32					41.80	42.01				
16	32.37	13.06	15.19	18.44	22.16	16.21	23.96	7.70	27.34	25.42
15	30.78	6.06	14.40	12.26	20.93	9.31	22.74	11.18	26.09	30.96
14	29.15	9.60	13.62	9.21	19.71	16.11	21.51	8.57	24.80	9.87
13	27.49	13.53	12.84	9.48	18.48	12.64	20.26	9.53	23.46	19.48
12	25.79	9.83	12.06	7.76	17.25	13.53	19.00	8.94	22.09	5.58
11	24.05	7.40	11.28	3.78	16.03	8.36	17.71	3.71		
7			8.15	15.67	11.12	16.68				
6			7.37	15.23	9.89	10.79	11.06	7.05	13.02	9.32
5			6.59	12.98			9.68	8.81	11.37	8.67
4			5.80	6.76	7.44	8.10	8.28	8.01		
3			5.02	0.89	6.21	6.14	6.86	7.02	7.95	1.59
1			3.46	0.6	3.75	1.08	3.99	3.50		

The results for the Tshwane study are presented in red and those for the Johannesburg study in black.

The results reveal that in contrast to the predicted DBH measurements showing increased growth (larger mean DBH measurements) related to the increase in age, the mean measurements of some of the trees did not follow the same pattern. The mean DBH measurements of the *C. erythrophyllum* trees in the Johannesburg study in years 11 to 15 were smaller than the mean measurements of the 5-, 6- and 7-year-old trees in the Tshwane study. The mean measurements of the 11-year-old trees in the Johannesburg study were smaller than the measurement of the 4-year-old trees in the Tshwane study. The mean DBH measurements of the *S. lancea* trees in the Johannesburg study for the 11- to 16-year-old trees were smaller than the DBH of the 7-year-old trees in the Tshwane study. The mean DBH measurements of the *O. europaea* subsp. *africana* trees in the Johannesburg study for the 16-year-old trees were smaller than the DBH of the 4- and 5-year-old trees in the Tshwane study. The 11-year-old *O. europaea* subsp. *africana* trees in the Johannesburg study were smaller than the 3- to 6-year-old trees in the Tshwane study. However, the 12- to 15-year-old trees were larger in the Johannesburg study than the 6-year-old trees in the Tshwane study. The mean DBH measurements of the *S. pendulina* trees in the Johannesburg study for the 12-year-old trees were smaller than the 5- and 6-year-old Tshwane trees and the 16-year-old trees in the Johannesburg study were smaller than the 15-year-old trees in the Tshwane study.

5.5.3.2 Applying the new allometric equations to predict other growth relationships

The results of the new growth relationships explained above, conducted with equations provided in Table 5.22 for the *C. africana*, *C. erythrophyllum, S. lancea, O. europaea* subsp. *africana* and *S. pendulina* trees, produced similar trends for all the species. To prevent repetitive results, the results of *S. lancea* (Figures 5.70 to 5.72) are presented to explain the concept. The results for the new allometric equations predicting other growth relationships (tree height from DBH, crown diameter from DBH and crown height from DBH) produced a positive increase in the relationships for all the trees. Using the new allometric equations to predict the other growth relationships, the R-squares ranged from 0.9791 to 1, indicating an ideal fitting linear relationship to the data for all the relationships. The reason for this is that the predictions of all the growth relationships are directly linked to DBH and different equations (available in Table 5.21) are only used with specific constant values for each of the equations.

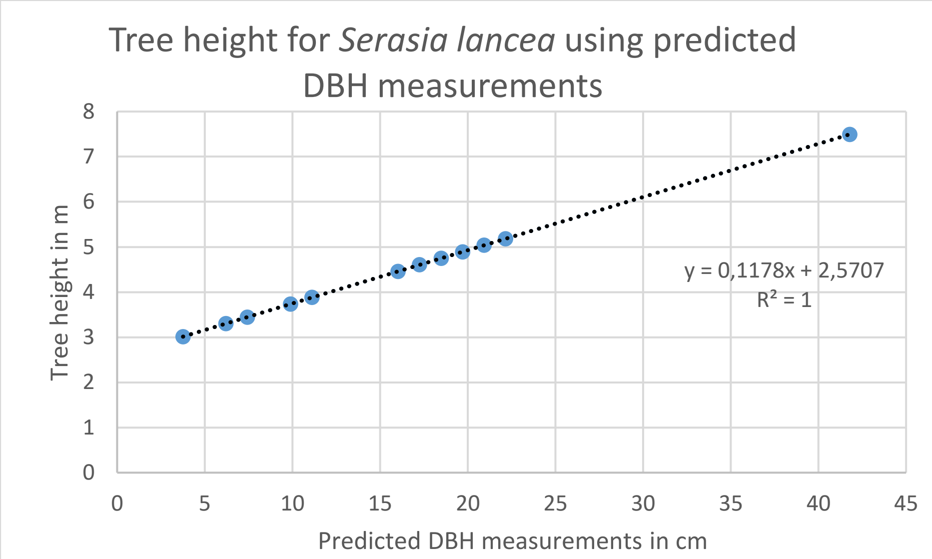


Figure 5.70: Perfect relationship/correlation between DBH and predicted tree height using linear equation for Searsia lancea

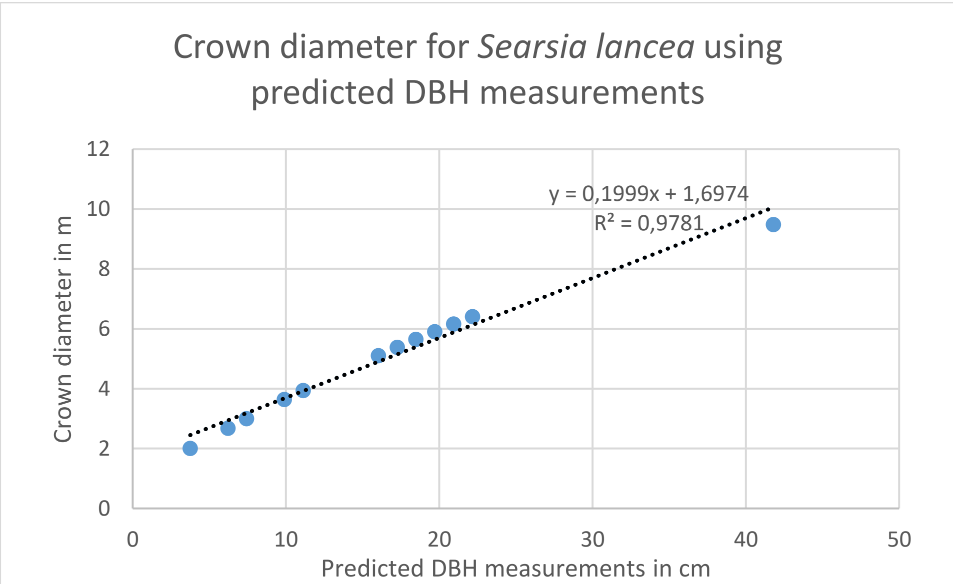


Figure 5.71: Strong fitting relationship between DBH and predicted crown diameter using quadratic equation for Searsia lancea

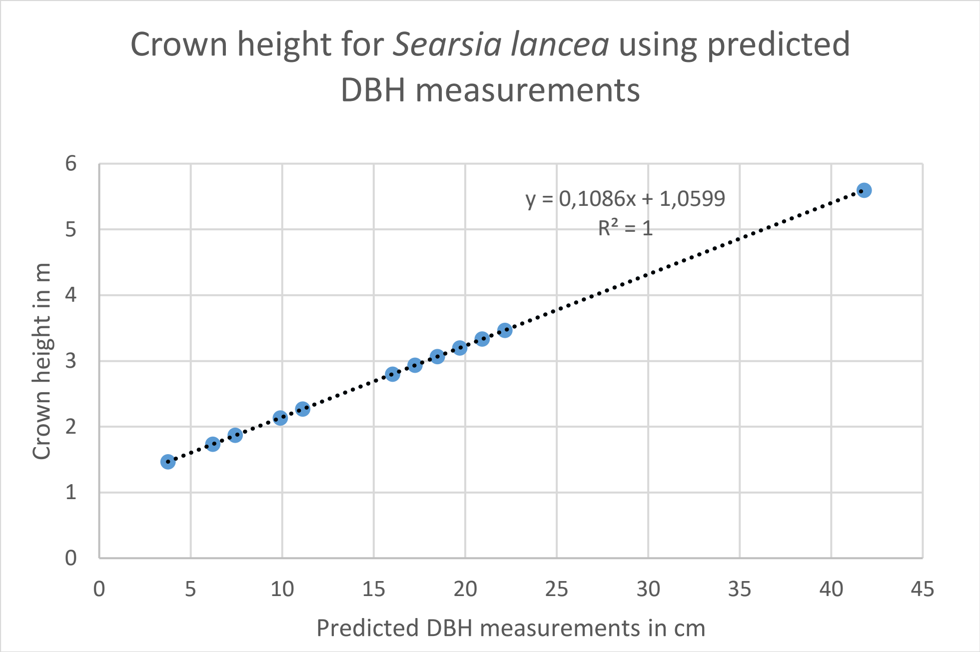


Figure 5.72: Perfect relationship/correlation between DBH and predicted crown height using linear equation for Searsia lancea

When using the DBH measurements of the study to replace the predicted DBH measurements for *S. lancea* and the new equations (from Table 5.21) to predict tree height, crown diameter and crown height, similar results were produced. Results for the DBH measurements of the study and predicted tree height using the linear equation are presented in Figure 5.73. The results for crown diameter using the quadratic equation are presented in Figure 5.74 and the results for crown height using the linear equation are presented in Figure 5.75.

Using the new allometric equations to predict these growth relationships using the DBH measurements from the study produced similar R-squares ranging from 0.9959 for the DBH and crown diameter relationship (Figure 5.74) to 1 for the DBH/tree height and DBH/crown height relationship (Figures 5.73 and 5.75, respectively). Both the DBH/tree height and DBH/crown height relationships had a linear trendline as the best fit and the DBH and crown diameter had a power trendline as the best fit. All these relationships indicate a strong to ideal fit to the data. The reason for this is that the predictions of all the growth relationships are directly linked to DBH and different equations (available in Table 5.21) are only used with specific constant values for each equation.

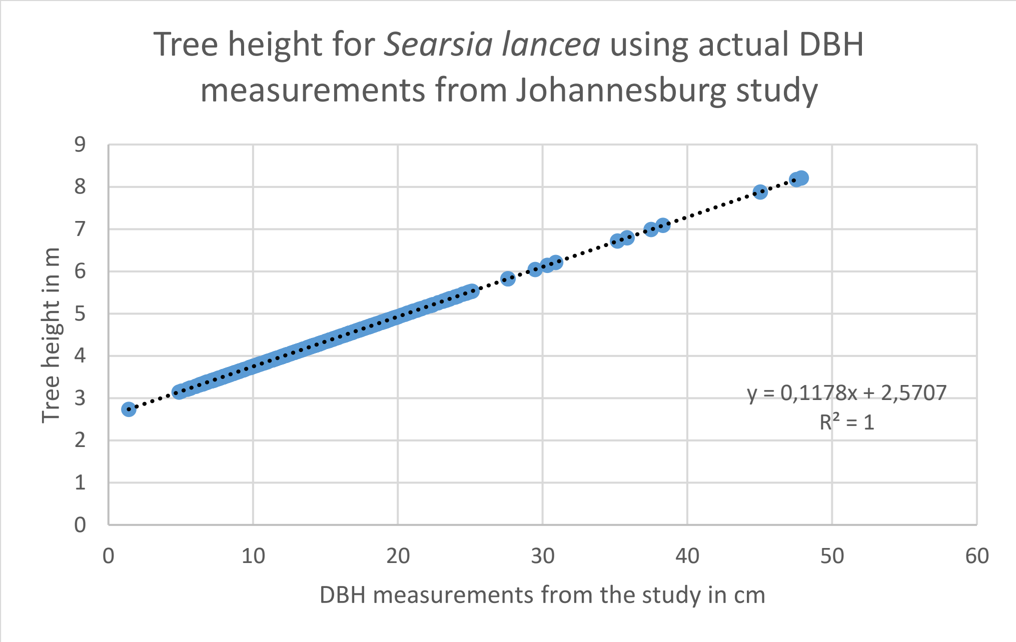


Figure 5.73: DBH data from study and predicted tree height relationship for Searsia lancea

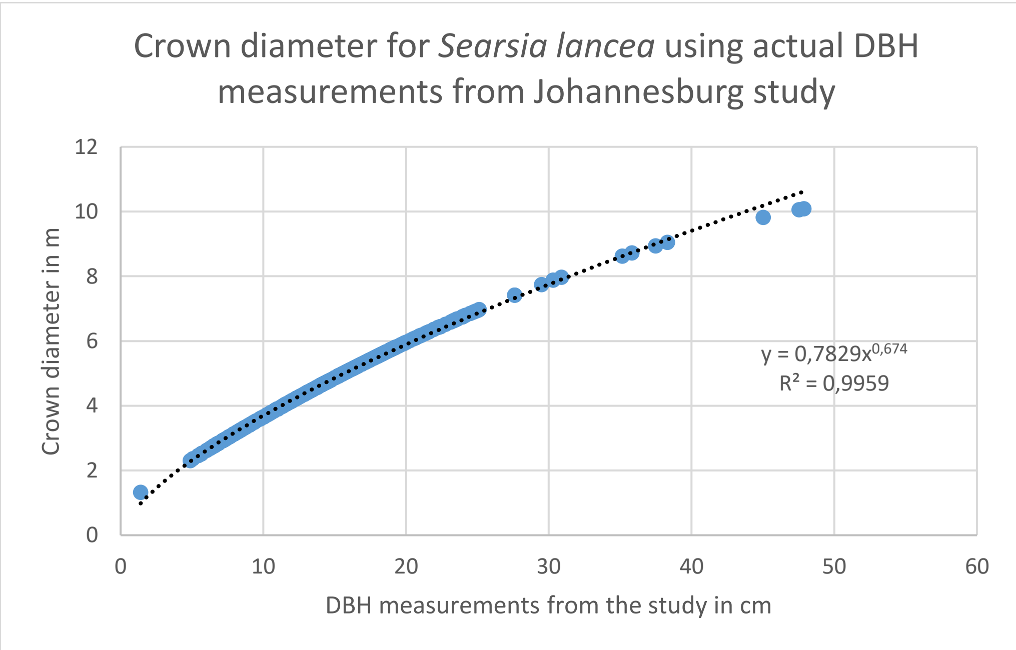


Figure 5.74: DBH data from study and predicted crown diameter relationship for Searsia lancea

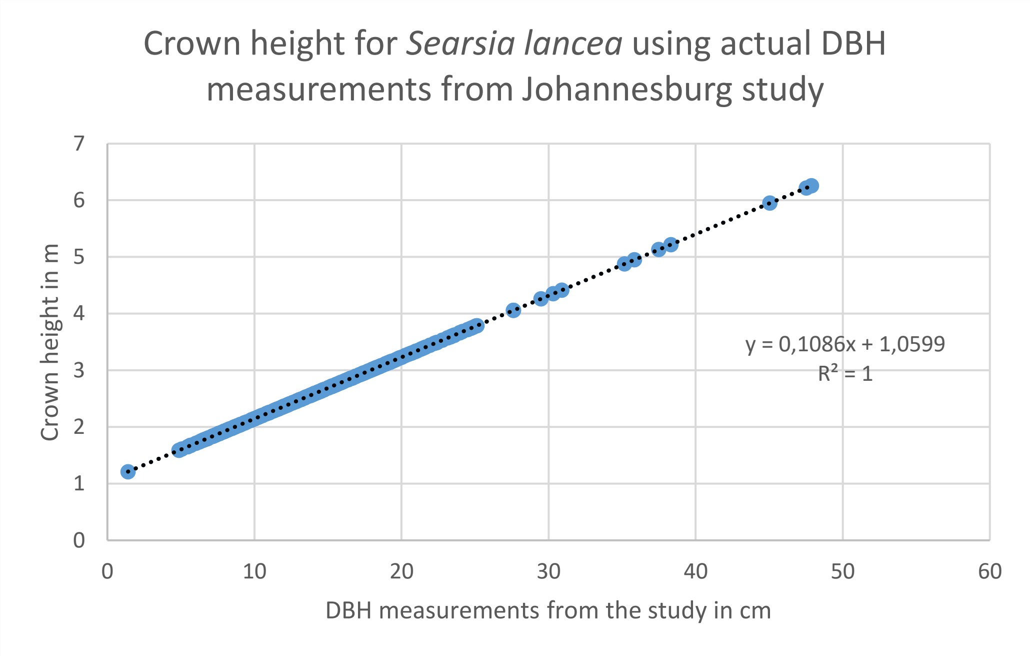


Figure 5.75: DBH data from study and tree crown height for Searsia lancea

5.5.3.3 Discussion: Difference between measurements and predicted measurements

The predicted DBH measurements for all the species illustrate an increase linked to age (Table 5.22). *Combretum erythrophyllum* and *S. pendulina* show similar increases in the mean DBH measurements, but *C. africana, S. lancea* and *O. europaea* subsp. *africana* do not follow the same pattern. The DBH measurements of all the trees in the Tshwane study also increase as the years increase, but those of the trees in the Johannesburg study do not always increase with age. The results imply that trees in the Tshwane study grew faster than trees in the Johannesburg study as the trees in the Johannesburg study were mostly smaller than the trees in the Tshwane study, although the latter are younger than the Johannesburg trees. This excludes the data for the trees older than 16 years only found in the Tshwane study. Most of the predicted measurements were smaller than the DBH measurements for all the species, indicating that these trees grow differently than predicted. This may be due to incorrect equations used to make the predictions, but may suggest anomalies and inconsistencies regarding the age data received from JCPZ for the trees in the Johannesburg study.

Comparing the results from the predicted growth relationship measurements obtained from the new allometric relationships above (Figures 5.73 to 5.75) with the results of the growth parameter relationship measurements for all the growth parameters measured during the field survey (Figures 5.11, 5.17 and 5.35) yielded the following outcome: The difference in the two sets of graphs is directly linked to the differences in the measurements of the tree heights, crown heights and maximum canopy diameters relative to the DBH measurements. The data from this study does not correlate with the predicted results. In the predicted DBH measurements, the DBH for *S. lancea* trees ranged from 3.75 cm to 41.8 cm (Figures 5.70 to 5.72), whereas the DBH data from this study ranged from 1.33 cm to 47.8 cm (Figures 5.73 to 5.75). Results produced by using the DBH measurements to predict tree heights ranged from 2.73 m to 8.71 m (Figure 5.73), whereas the data for the tree heights of the study ranged from 1.68 m to 5.63 m (Figure 5.11), with R^2 = 0.0998. Results produced by using the DBH measurements to predict crown diameter ranged from 1.46 m to 5.59 m, whereas the data from the study ranged from 1.3 m to 5.87 m (Figure 5.35), with R^2 = 0.4023. Results produced by using the DBH measurements to predict crown height ranged from 1.21 m to 6.25 m (Figure 5.75), whereas the measured data from this study ranged from 0.85 m to 4.45 m (Figure 5.17), with R^2 = 0.111.

From these results it can be deduced that the trees did not grow as predicted by research presented by McPherson et al. (2016). The predicted growth parameter measurements are in contrast to the data from this study as their predicted age or size is smaller than what their planting dates indicate they should be. The variation in the DBH and growth parameter predictions and the DBH and growth parameter data indicates inconsistencies in the JCPZ data but is also indicative of the variation in the growth of the trees.

5.5.4 Determining the correct ages for the trees in this study

McPherson et al. (2016) stress the difficulty of obtaining accurate age data for older trees as a limitation to the development of robust growth equations for urban trees. The results presented in this chapter highlight inconsistency in the age of the trees - the predicted DBH measurements did not correspond with the DBH data from this study. In this part of the study a final attempt was made to ascertain the correct ages of the trees by applying the “Tree age and correlated sequestrated carbon, stem circumference and stem diameter predictive table” (Stoffberg, 2006) for indigenous trees species to the measurements of this study. The predictive table provides circumference and diameter measurements taken at ground level (CGL and DGL). Therefore, for the purpose of this section the CGL measurements used as the raw data from this study are circumference. There is a strong correlation between CGL and CBH measurements, and therefore CGL was used in this part of the study.

Results are presented for the *C. africana*, *C. erythrophyllum, S. lancea, O. europaea* subsp. *africana* and *S. pendulina* trees. The CGL measurements of this study were linked to the mean CGL measurements in the table which identified a predictive age (in quarter years) for each of the DGL measurements. The results for *C. africana* are presented in Figure 5.76. These results are predictive, and therefore the strong relationship of the best fitting linear trendline (R^2 = 0.9866) indicated a very strong correlation with CGL and age. In comparison a logarithmic trendline (red dotted line) was fitted but presented an R^2 of 0.964. The predictive ages range from 1 to 17.5 years, whereas the age data from this study ranges from 11 to 16 years (Table 5.18) for the same CGL measurements. Comparing the predictive ages with the age data from this study reveals a 1.5-year difference in the ages of the oldest trees, but the predicted age indicates that most of the trees should be much younger than what the data from this study specifies, as there is a 10-year difference in the ages of the youngest trees.

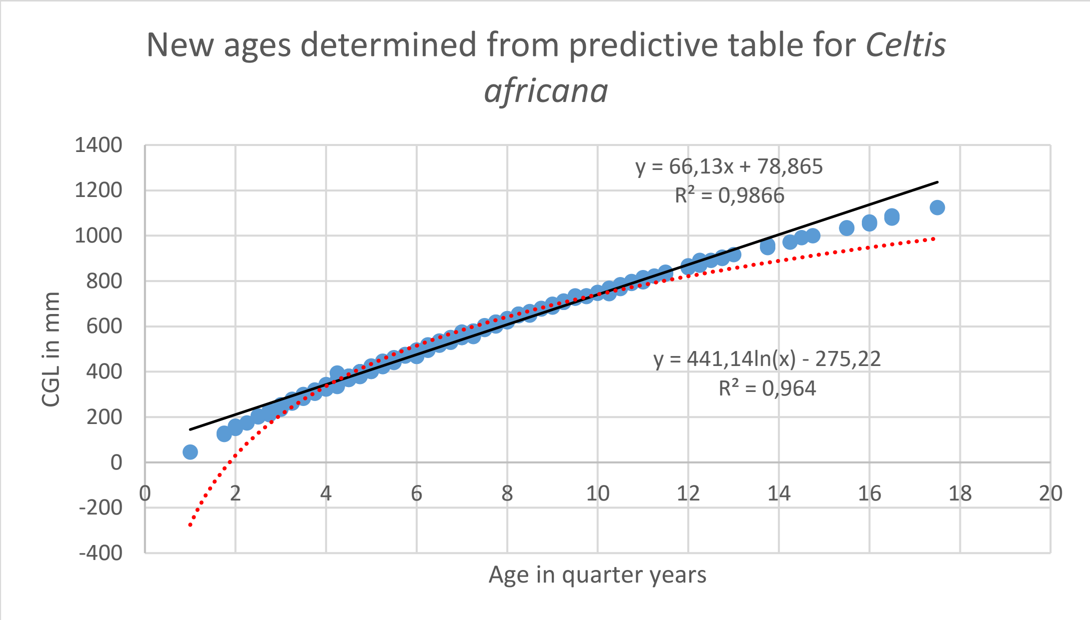


Figure 5.76: New ages in quarter years for Celtis africana

Results for the new ages linked to the CGL measurements of this study for *C. erythrophyllum* are presented in Figure 5.77. As these results are predictive, the R^2 of 0.9935 with a best fitting linear trendline indicates a very strong relationship with CGL and age. The predictive ages range from 1 to 19.25 years, whereas the age data from this study ranges from 11 to 16 years (Table 5.18). There is a 3.25-year difference in the oldest tree, but this could be an individual case as there was only one tree at that age. The predicted ages indicate that all the trees should be much younger than what the data from the study specifies, as there is a 10-year difference in the ages of the youngest trees.

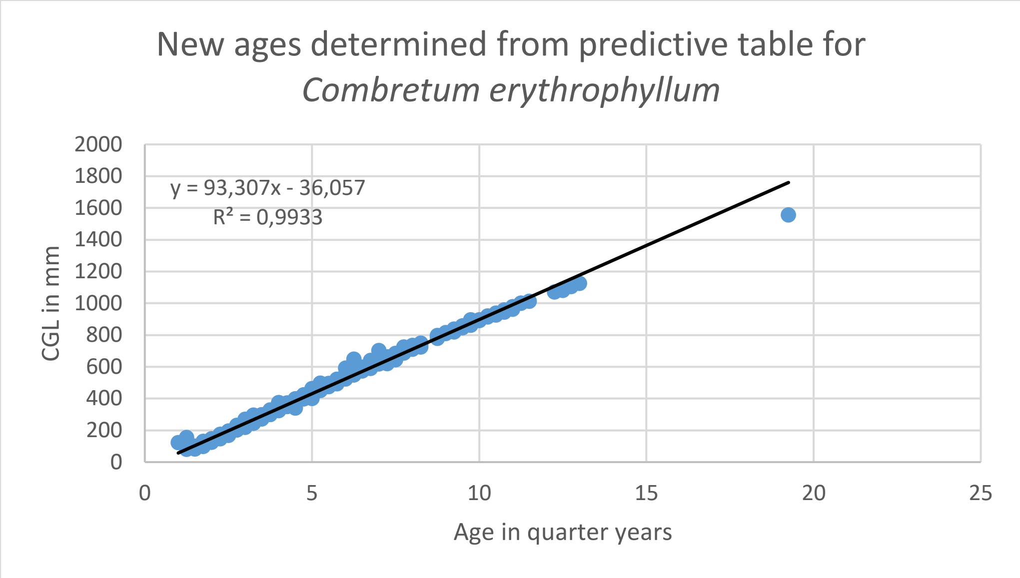


Figure 5.77: New ages in quarter years for Combretum erythrophyllum

Results for the new ages linked to the CGL measurements of this study for *S. lancea* are presented in Figure 5.78. The predictive results display a very strong relationship with CGL and age with R^2 = 0. 9741 for a linear trendline and 0. 9821 with a best fitting logarithmic trendline. The predictive ages range from 1.5 to 20.25 years, whereas the age data from this study ranges from 11 to 16 years (Table 5.18). There is a 4.25-year difference in the oldest trees and the predicted ages indicate that most of the trees should be much younger than what the data from this study specifies, as there is a 9.5-year difference in the ages of the youngest trees.

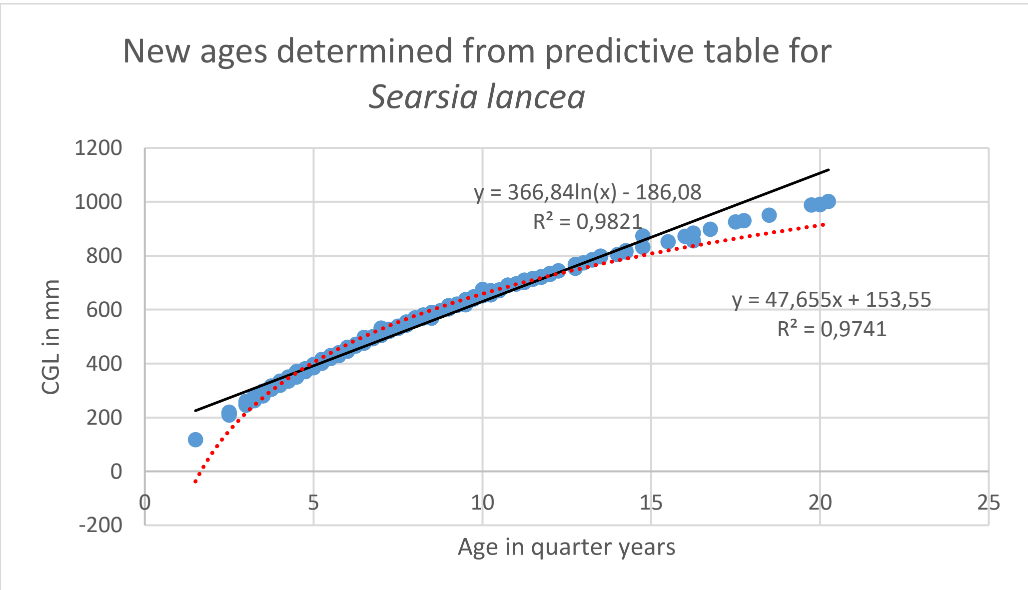


Figure 5.78: New ages in quarter years for Searsia lancea

Results for the new ages linked to the CGL measurements of the study for *O. europaea* subsp. *africana* are presented in Figure 5.79. The results show the R^2 of 0. 9933 with a best fitting linear trendline, indicating a very strong relationship with CGL and age. The predictive ages range from 1 to 19.25 years, whereas the age data from this study ranges from 11 to 16 years (Table 5.18). There is a 3.25-year difference in the oldest trees and the predicted age indicates that most of the trees should be much younger than what the data from this study specifies, as there is a 10-year difference in the ages of the youngest trees.

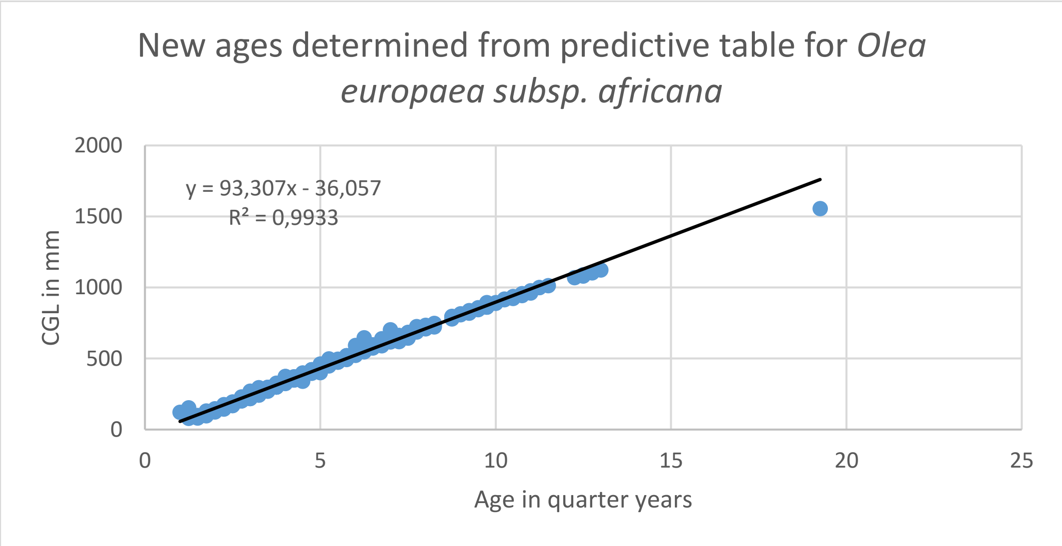


Figure 5.79: New ages in quarter years) for Olea europaea subsp. africana

Results for the new ages linked to the CGL measurements of the study for *S. pendulina* are presented in Figure 5.80. The predictive results produce an R^2 of 0. 9897 with a best fitting linear trendline, indicating a very strong relationship with CGL and age. The predictive ages range from 1.75 to 15.5 years, whereas the age data from this study ranges from 11 to 16 years (Table 5.18). There is only half a year's difference in the oldest trees and the predicted age indicates that most of the trees should be much younger than what the data from this study specifies, as there is 8.25-year difference in the ages of the youngest trees.

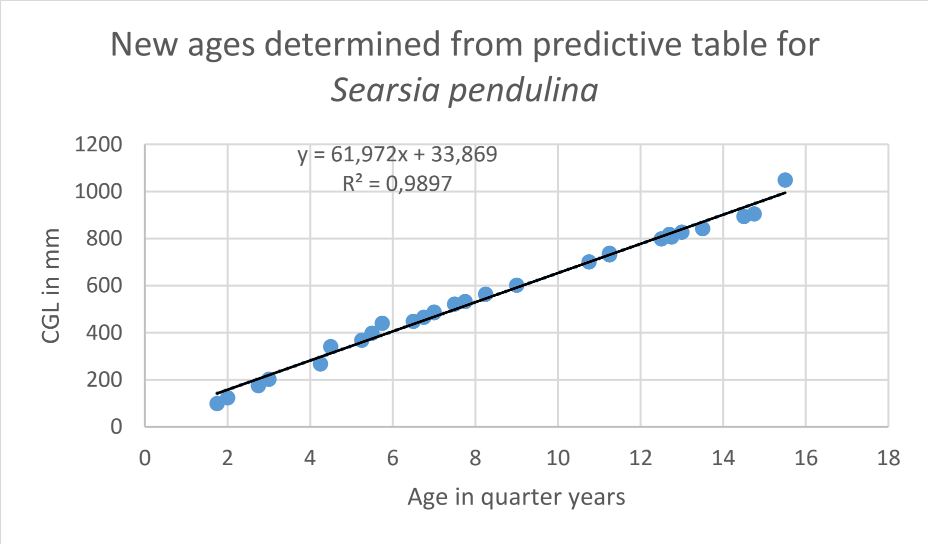


Figure 5.80: New ages in quarter years for Searsia pendulina

In summary, this attempt to establish the correct ages of the trees by applying the predictive table of Stoffberg (2006) using the CGL measurements of this study produced a different age profile for the trees than that of the measured data. The predicted ages for the oldest trees of all the species were a few years more than their age, indicating that there might be some trees that were older than indicated on the JCPZ tree register. They could have been planted prior to the date provided on the tree register, or they could have been much larger when they were planted. The planting specification of JCPZ was that the stem diameter (taken at 50 mm from the base of the trees) had to be a minimum of 30 mm on the day of planting and the tree height had to be 2 m from the base to the tip of the crown (Van der Merwe, 2016). A small number of trees fell into this category and can be seen as outliers in Figures 5.77 and 5.79. The results reveal that the predicted ages for most the trees of all the species were much younger than what the data in this study specifies, as the measurements of this study are much smaller than the predictive CGL measurements relative to age. The youngest trees in the study should be 11 years old but as can be seen in Figures 5.76 to 5.80, the youngest trees have predicted ages starting from 1 to 2 years. Similar to the statement above that some trees could have been larger at the time of planting, there could also have been trees that were smaller at the time of planting than specified by JCPZ. The smaller trees may also indicate slower growth than was experienced in the Tshwane study, which could be due to the difference in climate.

5.5.5 Using the new ages to improve the growth relationships

New ages were used to establish if the growth relationships could be improved. For comparison, a graph is provided to illustrate the relationship between the CGL data and the growth parameters for the trees of this study, with a second graph illustrating the relationship between the new tree ages and the growth parameters of this study. Results for the growth parameters of tree height and maximum canopy diameter are presented.

The relationship between the tree age data of this study and tree height (Figure 5.81) for *C. africana* produces an R^2 value of 0.0054 and a best fitting logarithmic trendline. The relationship between the new tree ages and tree height (Figure 5.82) delivered an R^2 value of 0.3215 and a best fitting linear trendline. The relationship between the tree age data of this study and the maximum canopy diameter (Figure 5.83) produced an R^2 value of 0.0216 and a negative best fitting power trendline. The relationship between the new tree ages and the maximum canopy diameter (Figure 5.84) delivered a graph with an R^2 value of 0.2406 and a linear trendline as the best fit. The new ages of the *C. africana* trees improved the R^2 values for age and tree height from 0.0054 to 0.3215 and for age and maximum canopy diameter from 0.0216 to 0.2406. However, these relationships are still weak.

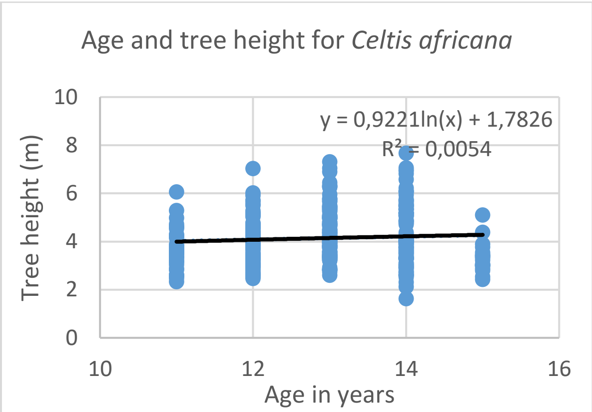


Figure 5.81: Age and tree height for Celtis africana *of this study*

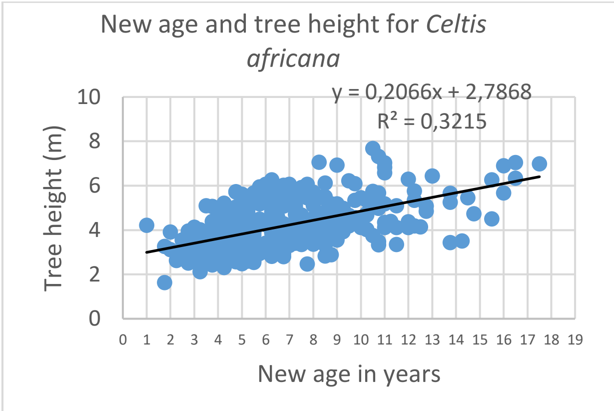


Figure 5.82: New age and tree height for Celtis africana *with new ages from Stoffberg (2006)*

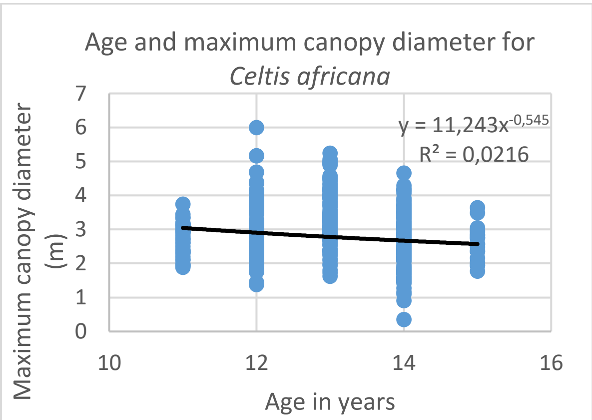


Figure 5.83: Age and maximum canopy diameter for Celtis africana *of this study*

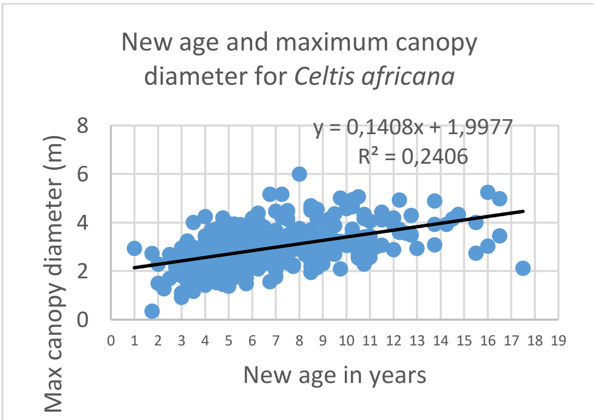


Figure 5.84: New age and maximum canopy diameter for Celtis africana *with new ages from Stoffberg (2006)*

The relationship between the tree age data of this study and tree height (Figure 5.85) for *C. erythrophyllum* produced an R^2 value of 0.0264 with a best fitting power trendline. The relationship between the new tree ages and tree height (Figure 5.86) provided an R^2 value of

0.2317 with a best fitting logarithmic trendline. The relationship between the tree age data of this study and the maximum canopy diameter (Figure 5.87) presented an R^2 value of 0.0562 with a best fitting linear trendline. The relationship between the new tree ages and the maximum canopy diameter (Figure 5.88) produced an R^2 value of 0.2568 with a logarithmic trendline as the best fit. The new ages of the *C. erythrophyllum* trees improved the R^2 values for age and tree height from 0.0264 to 0.2317 and for age and maximum canopy diameter from 0.0562 to 0.2568. However, these relationships remain weak.

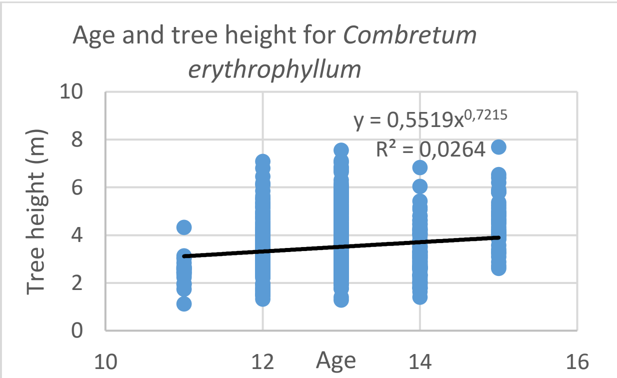


Figure 5.85: Age and tree height for Combretum erythrophyllum *of this study*

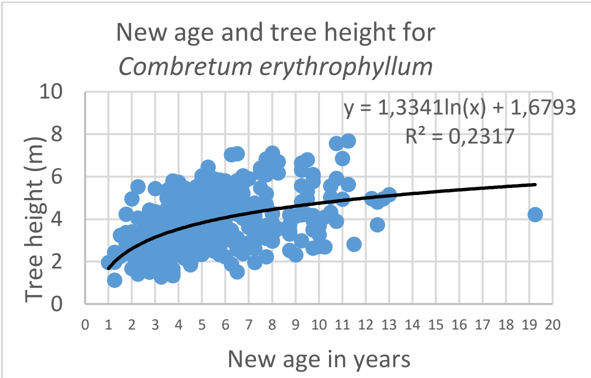


Figure 5.86: New age and tree height for Combretum erythrophyllum *with new ages from Stoffberg (2006)*

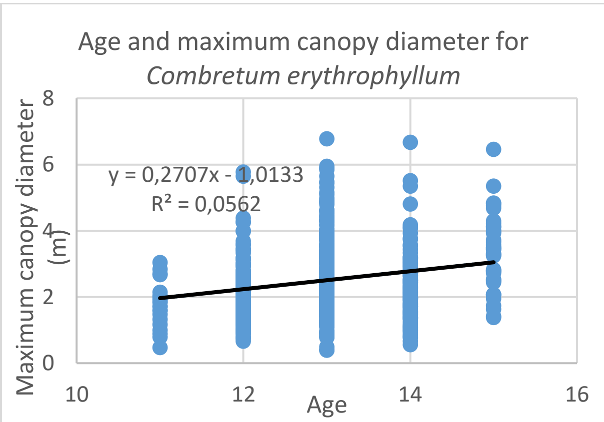


Figure 5.87: Age and maximum canopy diameter for Combretum erythrophyllum *of this study*

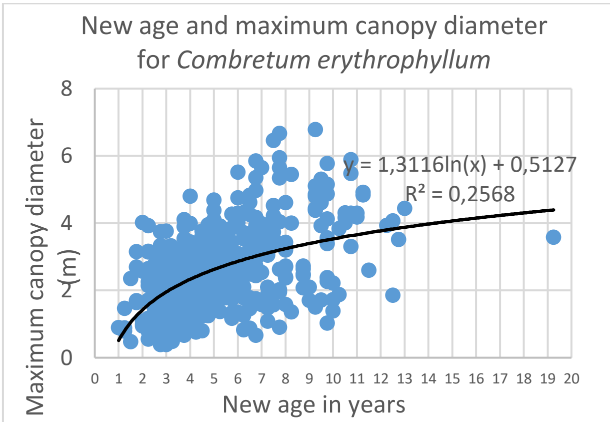


Figure 5.88: New age and maximum canopy diameter for Combretum erythrophyllum *with new ages from Stoffberg (2006)*

The relationship between the tree age data of this study and tree height (Figure 5.89) for *S. lancea* resulted in an R^2 value of 0.0049 with a best fitting exponential trendline. The relationship between the new tree ages and tree height (Figure 5.90) produced an R^2 value of 0.2273 with a logarithmic trendline as the best fit. The relationship between the tree age data of the study and the maximum canopy diameter (Figure 5.91) produced an R^2 value of 0.0178 with a best fitting exponential trendline. The relationship between the new tree ages and the maximum canopy diameter (Figure 5.92) produced a graph with an R^2 value of 0.4201 with a power trendline as the best fit. The new ages of the *S. lancea* trees improved R^2 values for age and tree height from 0.0049 to 0.2273 and for age and maximum canopy diameter from 0.0178 to 0.4201. However, these relationships are still weak.

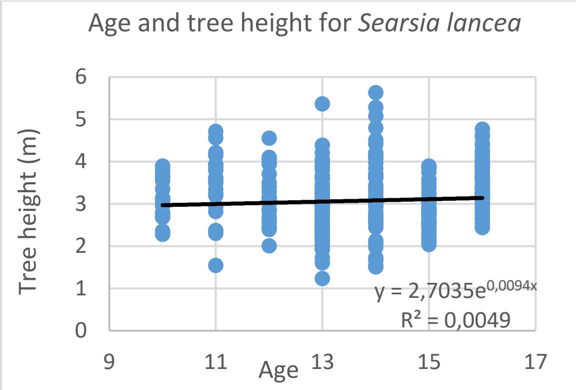


Figure 5.89: Age and tree height for Searsia lancea *of this study*

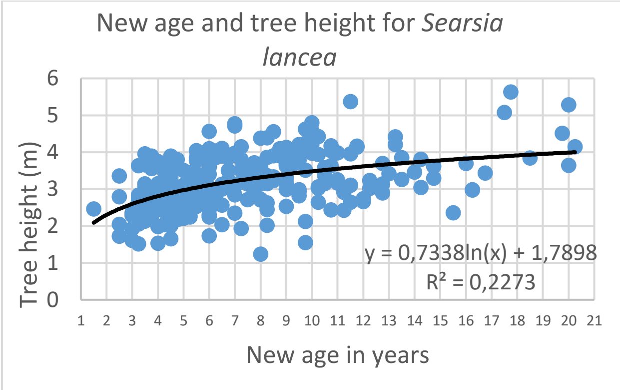


Figure 5.90: New age and tree height for Searsia lancea *with new ages from Stoffberg (2006)*

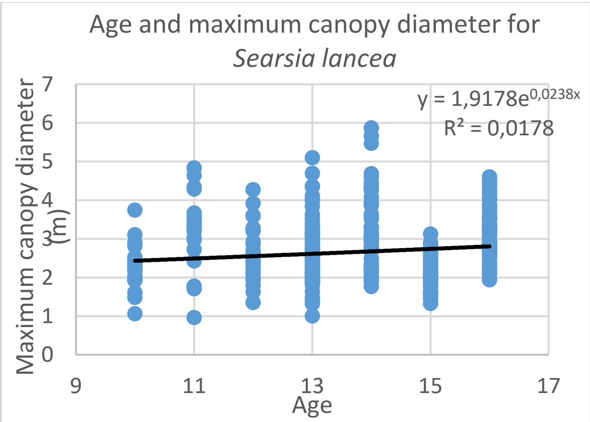


Figure 5.91: Age and maximum canopy diameter for Searsia lancea *of this study*

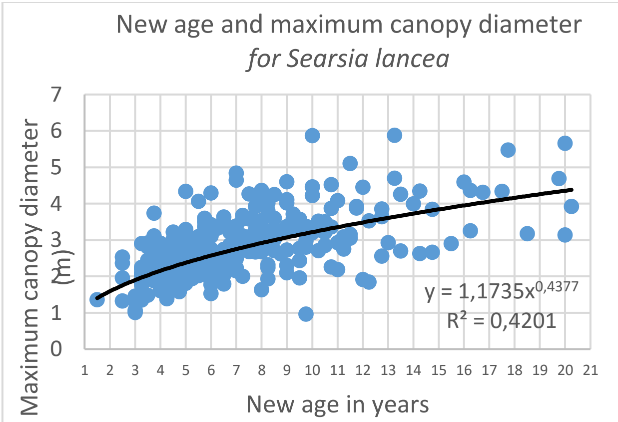


Figure 5.92: New age and maximum canopy diameter for Searsia lancea *with new ages from Stoffberg (2006)*

The relationship between the tree age data of this study and tree height (Figure 5.93) for *O. europaea* subsp. *africana* presented an R^2 value of 0.0121 with a best fitting linear trendline. The relationship between the new tree ages and tree height (Figure 5.94) produced an R^2 value of 0.1173 with a linear trendline as the best fit. The relationship between the tree age data of the study and the maximum canopy diameter (Figure 5.95) delivered an R^2 value of 0.0643 with a best fitting power trendline. The relationship between the new tree ages and the maximum canopy diameter (Figure 5.96) presented an R^2 value of 0.5224 with a best fitting power trendline. The new ages of the *O. europaea* subsp. *africana* trees improved R^2 values for age and tree height from 0.0121 to 0.1173 and for age and maximum canopy diameter from 0.0643 to 0.5224. However, these relationships remain weak.

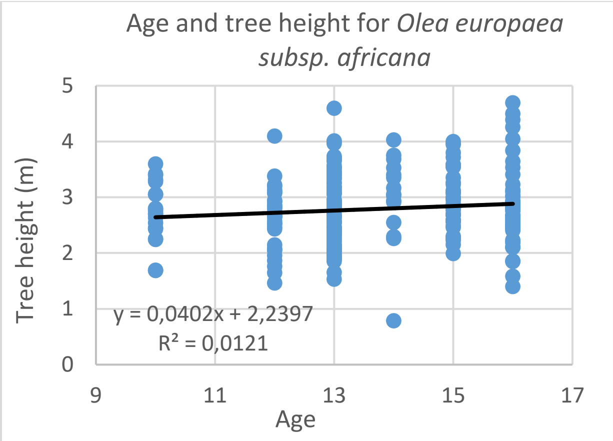


Figure 5.93: Age and tree height for Olea europaea subsp. africana *of this study*

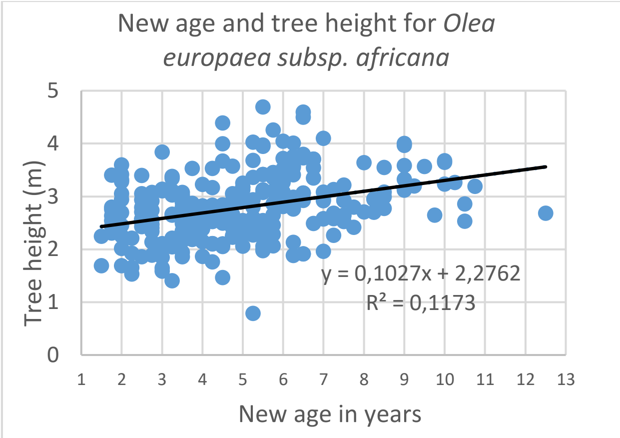


Figure 5.94: New age and tree height for Olea europaea subsp. africana *with new ages from Stoffberg (2006)*

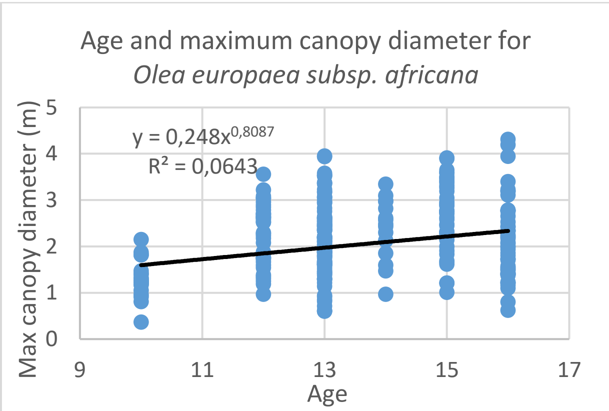


Figure 5.95: Age and maximum canopy diameter for Olea europaea subsp. africana *of this study*

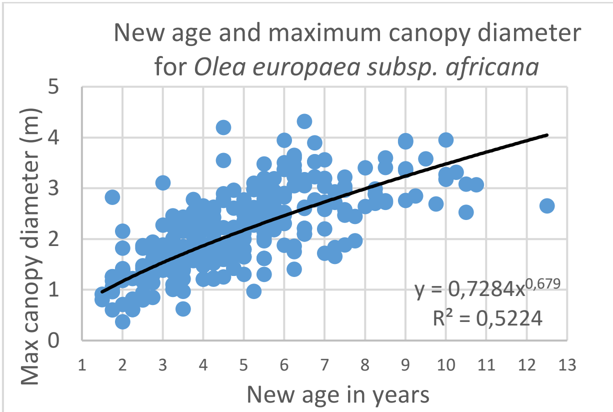


Figure 5.96: New age and maximum canopy diameter for Olea europaea subsp. africana *with new ages from Stoffberg (2006)*

The relationship between the tree age data of this study and tree height (Figure 5.97) for *S. pendulina* produced an R^2 value of 0.2045 with a best fitting power trendline. The relationship between the new tree ages and tree height (Figure 5.98) produced an R^2 value of 0.6476 with a power trendline as the best fit. The relationship between the tree age data of this study and the maximum canopy diameter (Figure 5.99) provided an R^2 value of 0.292 with a power trendline as the best fit. The relationship between the new tree ages and the maximum canopy diameter (Figure 5.100) produced a graph with an R^2 value of 0.7775 with a best fitting power trendline. The new ages of the *S. pendulina* trees improved R^2 values for age and tree height from 0.2045 to 0.6476 and for age and maximum canopy diameter from 0.292 to 0.7775. These relationships have the best R^2 values of the trees in the study and are moderate.

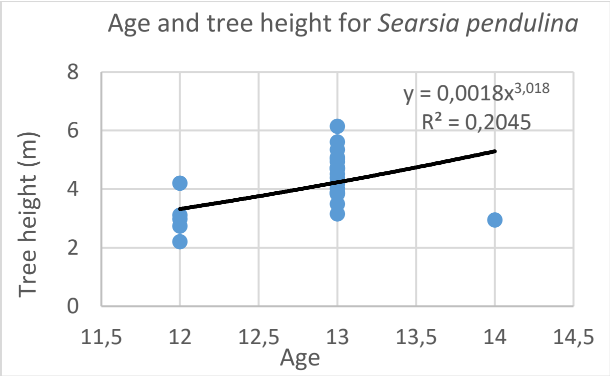


Figure 5.97: Age and tree height for Searsia pendulina *of this study*

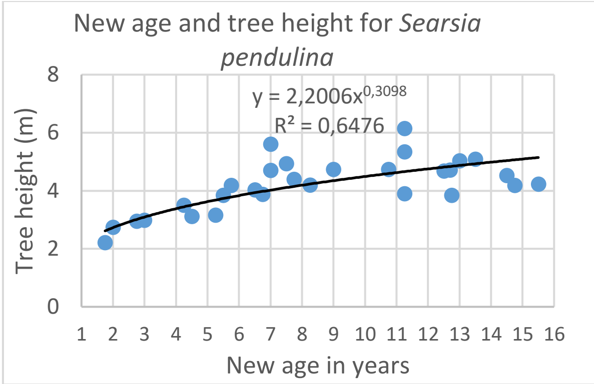


Figure 5.98: New age and tree height for Searsia pendulina *with new ages from Stoffberg (2006)*

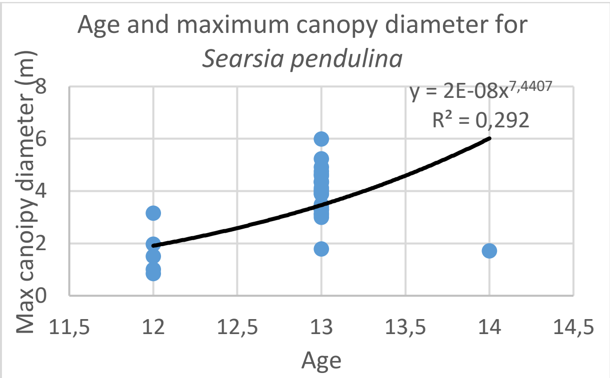


Figure 5.99: Age and maximum canopy diameter for Searsia pendulina *of this study*

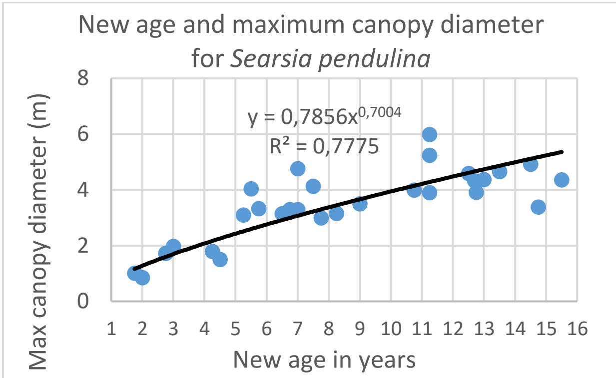


Figure 5.100: New age and maximum canopy diameter for Searsia pendulina *with new ages from Stoffberg (2006)*

Therefore, comparing the R^2 values of the relationships between the tree age and height data of this study with the new tree ages and heights, the R^2 values of all the species did improve but still produced weak relationships of less than 0.25 for *C. africana, C. erythrophyllum, S. lancea* and *O. europaea* subsp. *africana.* However, the R^2 value for the same relationship of *S. pendulina* improved to above 0.64, which is a moderate relationship. Comparing the R^2 values of the relationships between the tree age and maximum canopy diameter data of this study with the new tree ages and maximum canopy diameter data, the R^2 values of all the trees improved but still produced weak relationships of less than 0.42 for *C. africana, C. erythrophyllum* and *S. lancea.* The R^2 value for the same relationship of *O. europaea* subsp. *africana* improved to a moderate relationship of just above 0.50 and the R^2 value of *S. pendulina* improved to a strong relationship of above 0.77. Thus, the new ages from the predictive table (Stoffberg, 2006) can be used to predict the maximum canopy diameter of *O. europaea* subsp. *africana* and *S. pendulina*.

5.5.6 Discussion: The possibility of developing new allometric equations

The attempt to find a way to use the data from this study to develop new growth equations for these trees produced varying results. When the data from this study was combined with the raw data from the Tshwane study by Stoffberg (2006), there were improvements in the R-squares of the Johannesburg results, but the combination of the data reduced the high R^2 values of the Tshwane results for all the species. Combining the *C. erythrophyll*um and *S. pendulina* data produced weak growth relationships (R^2 = 0.2778 and R^2 = 0.3735, respectively), indicating that age cannot be used to predict the CGL of these trees and that factors other than age influence the growth of these trees. The R^2 results for *S. lancea* (0.4104) and *O. europaea* subsp. *africana* (0.5469) were improved to moderate relationships.

The development of new constant values for growth parameters by combining data from the Johannesburg and Tshwane studies using the logarithmic equation (Peper et al. 2001a, 2001b) yielded improved results compared to the results from this study. The relationships between CGL and age for *S. pendulina* (R^2 = 0.543), *S. lancea* (R^2 = 0.550) and *O. europaea* subsp. *africana* (R^2 = 0.959) were significant, as was the relationship between CBH and age for *O. europaea* subsp. *africana* (R^2 = 0.917) and produced moderate to strong R^2 values. The constant values (*A, b* and MSE) from the relationships above were subsequently tested to determine whether these values could be used for new growth estimations for these species. The calculations using the *S. pendulina* values did not produce a result. McPherson et al. (2016) indicate that equations predicting DBH from age may produce negative values for young trees and these negative values may cause obstacles when predicting variables. As shown in Table 6.21, the A (-21415.374) and b (-0.740) variables for this species were negative, providing the reason why the calculation could not be executed successfully.

The calculations using the *O. europaea* subsp. *africana* and *S. lancea* values produced results indicating that these new constant values can be used to determine growth rate equations for these species in Gauteng, South Africa. Growth rate equations for *O. europaea subsp. africana* did not exist in South Africa and this is therefore new and novel information developed by this study. Growth rate equations for *S. lancea* were developed for the city of Tshwane (Stoffberg, 2006). The equations developed in this study can be used for Gauteng therefore also constitute new information developed by this study.

Applying different growth equations by McPherson et al. (2016) to the abovementioned indigenous species of this study reveals that the predicted growth parameter measurements are smaller than what their planting dates indicate they should be. The predicted DBH measurements of the species demonstrated a constant increase in DBH with age; however, the DBH measurements of *C. africana, S. lancea* and *O. europaea* subsp. *africana* did not follow the same pattern. The results imply that trees in the Tshwane study grew faster than in the Johannesburg study, as the trees in the Johannesburg study are were mostly smaller than those in the Tshwane study even though the latter were younger than the Johannesburg trees.

Applying different equations to the data resulted in results that were similar to CGL vs age and CBH vs age results in this chapter. This demonstrates the concern about the correct ages of the trees. The difference in the growth compared to the ages in the Tshwane and Johannesburg studies confirms the statement of McPherson et al. (2016) that equations should be area specific as trees grow differently from one climatic region to another. These equations (McPherson et al., 2016) were developed in the northern hemisphere and might not be ideally suited for use in the southern hemisphere.

Comparing the results from the predicted growth relationship measurements obtained from the new allometric relationships with the results of the growth parameter relationship measurements of the tree heights, crown heights and maximum canopy diameter taken during the field survey yielded similar outcomes. The difference in the two sets of data is directly linked to the differences in the predicted and DBH measurements. The data from this study does not correlate with the predicted results. The predicted DBH measurement results indicate very strong relationships between DBH measurements and ages, whereas the results produced by using the DBH measurements to predict other growth parameters resulted in weak relationships. From this it can be deduced that the trees in this study did not grow as predicted by research presented by McPherson et al. (2016). The predicted growth parameter measurements are in contrast to the data from this study as the predicted age or size is smaller than what their planting dates indicate they should be.

In attempting to establish if the ages of the trees were correct by applying the predictive table of Stoffberg (2006) and to determine if the new ages could be used to improve growth relationships, it was deduced that the trees in Johannesburg did not grow as predicted by national and international scientific research (Stoffberg, 2006; McPherson et al., 2016). In all cases, the predicted age and size (CBH) of the trees were much younger and smaller, respectively, than what their planting dates implied. Even though there were a few trees that were predicted to be older than indicated on the tree register, most of the trees in the study were younger.

The differences in the mean CBH measurements compared to the predicted measurements of all the trees indicate either incorrect tree ages or inconsistent growth of the trees. Comparing the trees in the Johannesburg study to those in the Tshwane study reveals that the same age trees were smaller in Johannesburg than what they were in Tshwane. This may be attributed to the climate being a bit warmer with more precipitation per annum in Tshwane than in Johannesburg (information is provided in chapter 3), but may also be due to incorrect ages provided by the JCPZ tree register, trees not being the specified size at planting, different planting specifications and procedures as well as different maintenance procedures in the two cities. The Tshwane data was all measured in suburbs and the Johannesburg data was measured in a combination of suburbs and townships, which may have influenced the results as the observed growth environment in suburbs is often better than in townships.

McPherson et al. (2016) emphasise the need for correct ages in the development of growth equations and point out that the difficulty in obtaining correct age information restricts the use of growth predictions. This study confirms this statement as the difference in the predicted and actual ages in this study, expressed by the figures in section 5.5.4 of this chapter, indicates the differences in the coefficient of variance for the predicted and actual age and growth parameter relationships, limiting the creation of growth predictions.

5.6 General discussion

The interaction of growth parameters of the trees is statistically significant and the VolCalc software program and growth parameters: tree height (m), height of maximum canopy diameter (m), height at first leaf (m), maximum canopy diameter (m), stem diameter at first leaf (m) and volume (m^2) can be used to determine interaction.

The mean tree height measurements of the trees in the study confirm that the trees are still young as their mean heights were far below the mature height of each species as confirmed by Coates Palgrave (1983). McPherson et al. (2016) state that applying growth equations to tree data of young trees may produce negative values, which may cause continued problems for predicting tree height and other variables from DBH. They also mention that the presence of trees with dimensions that deviate from the norm can result in growth equations that produce less reliable size predictions. Semenzato et al. (2011) developed growth equation models for large tree species and confirm that it was difficult to estimate tree growth and relationships between age and stem diameter and between stem diameter and other growth dimensions, in smaller trees. This is of concern when trying to develop allometric equations for the trees in this study as they are young (between 11 and 16 years) and mostly smaller than they were predicted to be (sections 5.5.3 and 5.5.4).

There are statistically significant differences between the growth parameters of all of the trees in the study, but the results are not significantly different between the growth parameters of the trees in the different regions, indicating that regional differences did not affect the growth of the trees. The results did not provide conclusive data to identify a region where the trees were growing better or worse than in other regions, but they do indicate that Region C had larger trees and no trees with the smallest dimensions compared with any other region. When trying to identify reasons for the differences in the tree growth parameters for the different regions, the inconsistencies in the planting dates and ages of the trees were identified as a concern and it is suggested that the planting date and tree size information of the JCPZ tree register could possibly be incorrect.

There were statistically significant differences in the growth parameters of all the trees and their planting locations. The growth parameters of the trees planted in parks were larger than those of the trees planted in streets, indicating that trees grow better in parks and might suggest that street trees are under varied and greater stress than park trees. Trees growing in parks are often bigger and in better condition because they have not had root and canopy interference. Trees growing in medians or sidewalks often grow better or worse depending on the level of interference. Should tree growth be the only variable of concern, the preferred planting space would be in parks. Where street tree planting is concerned, some tree species grow significantly better on sidewalks in streets and others grow significantly better on medians of streets. It must be noted that tree age has not been taken into consideration to explain the differences in these locations.

Attempting to use the growth parameter data from VolCalc to develop growth equations for the trees in this study to determine which of the growth parameters can be used to predict growth established that there was a strong relationship between CGL and CBH of these trees. This indicates that CGL can be used to predict the CBH of the trees. Shackleton (1997, cited in Stoffberg, 2006) used DGL measurements in biomass regression equations for African savannah trees. Stoffberg et al. (2009) state that for African savannah trees the use of CBH (1.37 m above ground level) is not deemed to be appropriate for growth prediction as these species tend to branch lower than breast height. Tietema (1993, citing Dayton, 1978) used a stem measurement at "ankle height", that is 5-10 cm above the basal swell, to develop regression equations. However, this current study confirms that CBH can be used to develop growth equations, as there is a very strong correlation between the CBH and CGL measurements. This is also new information.

The growth curves of the trees in this current study did not compare with those of other research studies as the data points did not produce the typical logarithmic trendline shape. A possible explanation for the weak correlations and low R^2 values of the results of this study could be the variation in the mean tree heights resulting from the wide variety of tree heights relative to the tree ages. The differences in the tree heights over a 6-year growth period between the tallest and shortest *C. africana* is 6.12 m, for *C. erythrophyllum* the difference is 6.10 m, for *S. lancea* it is 4.40 m and for *O. europaea* subsp. *africana* it is 3.91 m, which appears to be too high for the period after planting. The concern is that the youngest trees are not the shortest and the oldest trees are not the tallest. The height/age relationships vary substantially. The variation in tree height may be for a variety of reasons, including different tree heights at the time of planting, the lack of structural and corrective pruning, location (land use and land cover as well as other site conditions such as conflict or the involvement of human activity) or environmental conditions. The only specification provided by JCPZ for the planting of these trees was the stem circumference of 30 mm on the day of planting (Van der Merwe, 2016), and no minimum tree height was specified. The original tree height at planting is therefore not known, resulting in inconclusive reasons for the results. The lack of structural pruning to shape tree canopies was evident throughout the study. This may negatively influence the growth and shape of the trees, affecting the range of the growth parameters. Another factor that was not incorporated in this study that may have an influence on the growth parameters is the different environmental conditions (precipitation, wind and pollution), or even the soil conditions in the different locations where the trees were planted.

Combining the data from this study with that from the Tshwane study and by applying different growth equations as presented in McPherson et al. (2016) was successful to develop new growth equations for certain species. Developing regression coefficients for the combined data provided improved results for *S. lancea, O. europaea* subsp. *africana* and *S. pendulina*. The relationships between CGL and age for *O. europaea* subsp. *africana* (R^2 = 0.959) and CBH and age (R^2 = 0.917) produced strong relationships, the best coefficients of determination (R-squares) and constant values (A, b and MSE). The relationships between CGL and age for *S. lancea* (R^2 = 0.550) and *S. pendulina* (R^2 = 0.543) produced moderate relationships. Coombes et al. (2019) developed growth relationships for trees with adjusted R^2 values below 0.60; new equations for *S. lancea* and *S. pendulina* were therefore attempted with *O. europaea* subsp. *africana.*

The calculations using the *S. pendulina* values produced errors and were not pursued further. New growth rate equations were derived from the calculations for *O. europaea* subsp. *africana* and *S. lancea*. Growth rate equations for *O. europaea* subsp. *africana* did not exist before in South Africa and this is therefore new information developed by this study.

As these equations were developed by combining data from both the cities of Tshwane and Johannesburg, the equations are applicable to the climatic region where these two cities are found. These cities are in the Gauteng province in a summer rainfall region and have similar climates, although Tshwane to the north of Johannesburg is approximately two degrees warmer due to its lower altitude (1 339 m). The other local authorities in the province to the west (West Rand at 1 740 m), east (Ekurhuleni at 1 600 m) and south-east (Sedibeng at 1 521 m) of Johannesburg are on a similar interior plateau at an altitude of 1 694 m above sea level. The entire Gauteng province is classified by the Kőppen-Geiger Climate Classification as a warm temperate climate with a dry winter and a warm summer (CSIR, 2015) and most of the province forms part of the Bankenveld veld type classification (Bredenkamp & Brown, 2002) or what is referred to as a combination of the Dry Highveld Grassland Bioregion and the Mesic Highveld Grassland Bioregion (Rutherford, Mucina & Powrie, 2006). Therefore, the growth rate equations of *O. europaea* subsp. *africana* and *S. lancea* can be used for Gauteng and this is thus new information developed by this study.

The different growth equations by McPherson et al. (2016) produced conflicting results highlighting, firstly, the inconsistency in the results of this study with regard to the ages of the trees, as the ages do not correlate with the DBH, tree height and other parameter measurements. Secondly, the DBH vs age results were similar to the CGL vs age and CBH vs age results, which substantiates the correlation between diameter and circumference measurements and the concern with regard to the correct ages of the trees. Thirdly, the results confirm the statement of McPherson et al. (2016) that equations should be area specific as trees grow differently from one climatic region to another. The results did reveal that even though the two cities are in the same climatic region, the Tshwane trees were growing faster than the Johannesburg trees. Location aspects may have contributed to the difference in growth, as the Tshwane trees were mostly planted in managed lawn residential areas (Stoffberg, 2006) and the trees in Johannesburg were not. The trees in Tshwane were also mostly pruned (which induces new shoot growth) and watered during the first two years of establishment after planting. Details of the location of the trees in the Johannesburg study are provided in Chapter 7 of this thesis.

The new age and CBH measurements that were established by applying predictive equations and tables indicate that the growth of the trees in Johannesburg was less than predicted. Studies have found that young trees and trees with small diameters are impacted more by urban site attributes than mature trees and trees with larger diameters (Quigley, 2004; Nowak et al., 2004). The variation in the new age and CBH predictions and the data from this study demonstrates inconsistencies in the growth of the trees, which may be due to a range of factors such as climate and age at planting, but may also be due to stress factors. All urban trees are affected by everyday urban stressors such as the effect of air pollution, insufficient space for proper root growth, a lack of nutrition (Merse et al., 2009), exposure to wind, restricted rooting space, soil compaction and ineffective drainage (Coombes et al., 2019).

Nevertheless, international research indicates that the growth of urban trees may also be affected by soil structure of the tree pit and the use of organic amendments during planting and the establishment of trees (Vidal-Beaudet et al., 2018), a clear official tree planting policy that specifies tree planting sites, species selection, planting procedures and maintenance

(Jim, 1993), funding, tree care and long-term maintenance (Pincetl, 2010; Roman et al., 2014b), tree planting technique (Yang & McBride, 2003), improper planning and management mechanisms (Deb et al., 2013), poor management and incorrect use of tree support and protection systems (Thacker et al., 2018).

With regard to this study, the following may have affected the growth of the trees: The tree specification may not have been detailed and exact enough. The planting specifications and procedures may not have been sufficient to ensure consistent growth of these trees. The planting budget or funds may have been restricted, resulting in limited funds for immediate and long-term maintenance. The maintenance specification may not have been detailed and exact enough, or the maintenance was not implemented as specified, or no long-term maintenance was specified. This information is not available and can only be speculated upon.

5.7 Conclusion

The study aimed to determine the interaction between growth parameters of the trees of the GSTP project, to determine whether VolCalc can be used for these calculations and to develop new allometric equations for individual species.

Based on the growth parameter results of the study, it can be concluded that there are no differences in growth of the trees between the different regions of the city, but trees in parks grow better than street trees, and trees planted on medians grow better than those planted on sidewalks. This study has indicated that should JCPZ attempt another large tree planting project, they should plan the tree planting in all the regions of the city as they can expect similar growth across all regions. This study confirms the results of McPherson (1992) by revealing that trees found in parks have higher growth rates than those found in streets and points out the importance of planting trees in parks as a first option in an urban environment. The study further identified that *C. africana* trees should rather be planted on sidewalks than on medians, *S. lancea* trees should preferably be planted on medians and *C. erythrophyllum* may be planted on sidewalks or medians as they would grow well in both locations. *Olea europaea* subsp. *africana* trees should only be planted in parks as they do not grow well on sidewalks or on medians. This knowledge was not available to JCPZ prior to this study and should be used to guide future tree planting decisions.

This study established a strong relationship between the growth parameters of CGL and CBH, indicating that CGL can be used to predict the CBH of indigenous trees. Therefore, both CGL and CBH can be used to develop regression equations for African savannah trees, which is new information. However, it must be noted that the CBH measurement often involves measuring more than one stem as these trees tend to branch below 1.37 m above the ground, which could lead to inaccuracies if not conducted with care. The CGL measurement mostly involves one stem measurement, reducing the chance for errors.

VolCalc was successfully used to provide data for the interaction of the growth parameters for the species of this study. It can be used to replace clinometers and tapes (Peper et al., 2001a, 2001b; Stoffberg et al., 2006,2009; Shackleton & Scholes, 2011), a plummet as described by Pretzsch, Biber, Uhl, Dahlhausen, Rotzer, Caldentey, Koike, Van Con, Chavanne, Seifert, du Toit, Farnden, & Pauleit, (2015) and an Abney level to establish tree heights via trigonometric conversion (Shackleton & Scholes, 2011) for urban trees. As it requires only a digital camera and object of known size, it is a swift and rigorous method for collecting tree dimension parameter data. However, the software program does not calculate DGL, CGL, DBH and CBH, which will still require either a tape measure or calliper to measure.

Researchers state that the information from allometric equations can be used by urban forest managers to develop policies, plan new tree planting and establish best management practices for the selection, planting and maintenance of trees (McPherson et al., 2000; Peper et al., 2001a, 2001b; Stoffberg et al., 2008). Even though allometric equations could not be developed using just the data from this study, the data can be used to inform tree planting strategies or guidelines and develop management practices and procedures for tree selection, planting and maintenance. The mean maximum canopy diameter growth parameter for each of the species can be used to indicate the minimum planting distances of the trees, the height at first leaf data can be used to indicate pruning needs for crown lifting to a specified height that would accommodate pedestrian movement next to street trees, and tree height can be used to indicate pruning needs close to overhead cables and structural elements.

New growth rate equations were developed for *O. europaea* subsp. *africana* and *S. lancea*. These equations are applicable to Gauteng, South Africa. These results could be used for predicting the physical dimensions of these species to assist in planning future tree planting by indicating how far apart the trees should be spaced in parks and on medians or to determine the distance these trees should be planted from structures such as buildings, bridges or street lights. A literature search revealed no information related to the growth of *O. europaea* subsp. *africana* in Gauteng, which depicts this information as new and novel. This information can be used to establish the value of carbon and other economic benefits in future.

Findings were made that question the correctness of the ages of the trees, as there are substantial variations in the age/growth relationships. International studies have found that the growth and condition of young trees are markedly impacted by urban, location and site attributes (Jim, 1989; Dobbs et al., 2013). Therefore, further research was conducted to identify the implications of the effect of the land cover, land use and other site factors on the growth of these trees. These results are presented in Chapter 7.

CHAPTER 6

CARBON VALUE OF GREENING SOWETO PROJECT TREES

6.1 Introduction

The results of the value of the trees of the Greening Soweto Tree Planting (GSTP) Project are presented and discussed in this chapter. A carbon assessment was conducted and yielded results on the quantity of the standing carbon stocks contained in the trees. The standing carbon stocks refer to the carbon stocks contained in the measured trees at the time of measurement in 2017. These results include an assessment of the carbon stocks of all the trees measured for all the species and for the individual species in each of the regions in the city. The data yielded results for the monetary value of the standing carbon stocks and the difference in the total carbon stocks and carbon value of these trees, the trees on the tree register and an estimation of the trees alive in 2017 for the whole project. The carbon value is presented as a carbon tax value of ZAR120,00 per metric ton of CO_2, proposed by the National Treasury (Department of National Treasury, 2013) and a hypothetical estimation of US$10 per ton CO_2e. Thereafter, the standing carbon stocks are extrapolated over a 30-year period and presented for different tree estimation scenarios. International data is then discussed.

The carbon assessment was conducted by measuring tree circumferences of randomly selected individual trees and applying the growth relationship equations from the Tshwane study by Stoffberg (2006). These are the only growth equations found in literature currently existing for indigenous urban trees in South Africa. The aim was to have a standard error percentage of less than 3% in the results. Results on the standard error calculations are presented as a precursor to the carbon results.

6.2 Standard error

The results for sample inventory to determine the standard error (SE) percentage, if 20 trees per species, per suburb is used as the sample size, are presented and discussed. The data from Region C was used to determine the SE percentage (Table 6.1), portraying the SE percentage of the mean CGL per suburb for each tree species and the corresponding mean CGL per tree species, per suburb. Results are presented for 10 or more trees per species per suburb. All the tree species per suburb were added and the standard error percentage for the tree species was calculated.

Collecting data from 20 trees per species per suburb resulted in a low mean standard error of less than 4% per species for *C. africana*, *C. erythrophyllum*, *S. lancea, S. pendulina* and *O. europaea* subsp. *africana. Harpephyllum caffrum* (SE% = 4.64) and *S. pendulina* (SE% = 6.71), highlighted in orange in Table 6.1, were the only trees measured where the SE was more than 4%. The mean SE for *H. caffrum* was 4.64% but only 10 trees (with an average CGL of 338 mm) were measured in this study, as these were the only trees of the species that could be found in the suburb. Even though more than 20 *S. pendulina* trees (n = 22) were measured in the suburb Manufacta, the mean SE for the trees in that suburb was high (6.71%). This was due to the high variation in the sizes of these trees. The mean SE for the trees, including the *H. caffrum,* was 2.49% and excluding the *H. caffrum*, the SE was 2.06%. Therefore, the lowest SE included data from only 10 trees measured (for one species in the region) in the sample. The mean CGL measurements are displayed in Table 6.1 as they were used to determine the SE. The differences in these measurements are not discussed, as they were dealt with in Chapter 5.

Nowak et al. (1996) and Nowak et al. (2015) state that the lower the standard error, the greater the confidence in the estimation of the carbon and the precision of the estimate. The low percentage SE indicated that 20 trees per species, per suburb, provided a sufficiently acceptable representative sample of the mean stem circumference of the trees planted in the suburb and confirmed that 20 trees per species, per suburb, was sufficient to provide the required data from which significant results for the carbon calculations part of the study could be determined.

Table 6.1: Percentage SE of CGL mean per suburb per tree species in Region C

SUBURB	*Celtis africana* %SE	**CGL Mean circumference**	*Combretum erythrophyllum* %SE	**CGL Mean circumference**	*Searsia lancea* %SE	**CGL Mean circumference**	*Olea europaea subsp. africana* %SE	**CGL Mean circumference**	*Harpephyllum caffrum* %SE	**CGL Mean circumference**	*Searsia pendulina* %SE	**CGL Mean circumference**
Constantia Kloof	1.77	649	1.96	649			3.38	372				
Cosmo City North 1	2.76	496	2.57	626			2.86	429				
Cosmo City North 2							1.76	429				
Cosmo City North 3			1.43	555			2.66	519				
Cosmo City South 1			1.50	479	2.55	495	3.80	394				
Cosmo City South 2	2.49	665			1.74	747	2.90	552				
Cosmo City South 3			1.86	889	1.37	514	2.30	493			2.89	394
Horison View	1.05	489	2.20	537			3.89	192	4.64	338		
Manufacta			1.71	264							6.71	226
Northriding	1.62	395	1.61	220								
Princess Agricultural Holdings			2.98	209								
Randpark Ridge			2.65	234	2.48	356						
Strubensvalley	2.32	443										
Tsepisong	2.16	342	1.60	321								
Weltevreden Park					2.7	723						
Wilgeheuwel	2.93	584	3.90	244	2.96	697						
Witpoortjie	2.62	532	1.15	319								
Mean SE %	**2.75**		**1.59**		**1.46**		**1.11**		**4.64**		**3.43**	
Mean circumference		**565**		**414**		**566**		**423**		**338**		**310**
Total number of trees per species	**219**		**282**		**122**		**163**		**10**		**28**	

The corresponding mean CGL measurement is provided for reference.

6.3 Standing carbon stocks

To calculate the standing carbon stocks and the carbon-based value of the GSTP project, a total of 2 489 indigenous trees were measured. The locations of these trees are indicated on the map in Figure 6.1. The results of the standing carbon stocks of the trees are presented for each individual tree species in the study, for each region and for the different years of planting. Furthermore, the results highlight the differences in the carbon stocks for the street trees (sidewalks and medians) and park trees and are presented for *Afrocarpus falcatus* (n = 40), *Celtis africana* (n = 834), *Combretum erythrophyllum* (n = 732), *Harpephyllum caffrum* (n = 10), *Kiggelaria africana* (n = 9), *Olea europaea* L. subsp. *africana* (n = 347), *Podocarpus* species (n = 18), *Schotia brachypetala* (n = 20), *Searsia lancea* (n = 379), *Searsia pendulina* (n = 45), *Senegalia galpinii* (n = 41), *Vachellia karroo* (n = 3) and *Vachellia sieberiana* var. *woodii* (n = 20).

As 20 trees per species per suburb of *H. caffrum* (n = 10), *K. africana* (n = 9), *Podocarpus* spp. (n = 18) and *V. karroo* (n = 3) species could not be found to measure, the trees that were found were measured. Therefore, standing carbon stock results are presented for the total number of trees measured (n = 2 498; SE 2.49%) and the total without the species with fewer than 20 trees per species per suburb measured (n = 2 457; SE 2.06%), to identify which standard error should be used for the study. The difference is given between the results of the total carbon stocks and value for all the standing trees measured, per tree species with a standard error of 2.49% (Table 6.2) and the results of the total carbon stocks and value of the measured trees, minus the trees with fewer than 20 trees measured as per standard error 2.06% (Table 6.3).

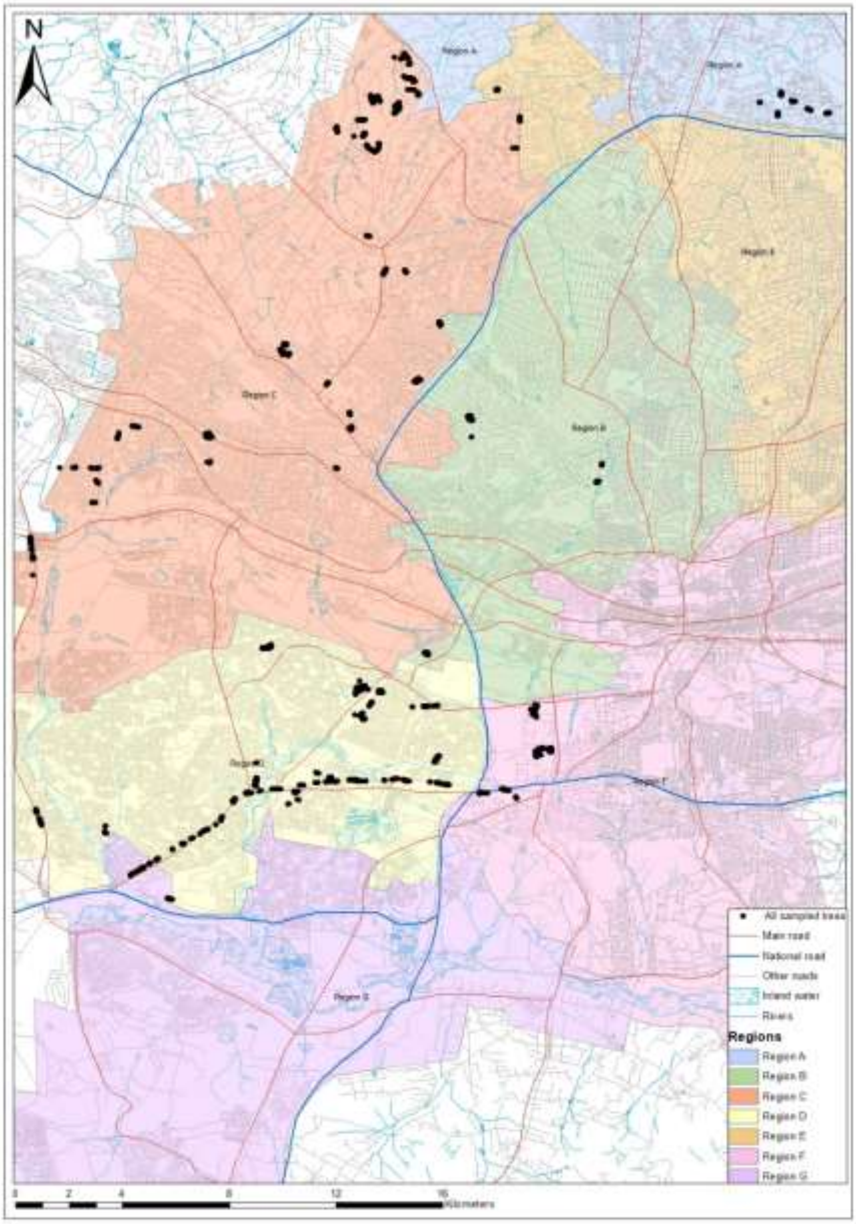


Figure 6.1: Individual trees measured in the study, with different regions in different colours

6.3.1 Standing carbon stocks for each tree species

The standing carbon stocks are presented for the individual tree species and an SE% of 2.49 (Table 6.2). The results illustrate the number of trees measured for each species, the total standing carbon stocks per tree species in kilograms and the mean carbon per tree species in kilograms. The total standing carbon stocks were multiplied by the factor 3.67 to provide the total standing CO_2 in kg for each species and the CO_2 in kg was converted to metric tons (tCO_2). Thereafter the value was determined by multiplying the tCO_2 by R120 to determine the ZAR value and US$10 to determine a hypothetical US$ estimation. Results in Table 6.2 are provided for each tree species indicating the number (n) per species, total standing carbon stocks for the trees measured in kg, the mean carbon per tree species in kg, the total CO_2

measured in kg and in tCO_2, the tCO_2 percentage contribution and the value in South African rand and US dollars.

Table 6.2: Total standing carbon stocks of each tree species (SE 2.49%)

Tree species	n	Total standing carbon stocks (kg)	Mean carbon (kg)	Total CO_2 (kg)	Total CO_2 (tCO_2)	% tCO_2	ZAR	US$
Afrocarpus falcatus	40	894.41	22.36	3 282.50	3.28	0.86	393,90	32.82
Celtis africana	834	44 341.29	53.17	162 732.53	162.73	42.83	19 527,90	1,627.32
Combretum erythrophyllum	732	27 751.13	37.91	101 846.65	101.85	26.80	12 221,60	1,018.46
Harpephyllum caffrum	10	136.24	13.62	500.00	0.50	0.13	60,00	5.00
Kiggelaria africana	9	156.50	17.39	574.36	0.57	0.15	68,92	5.74
Olea europaea subsp. *africana*	347	7 642.79	22.03	28 049.04	28.05	7.38	3 365,88	280.49
Podocarpus spp.	18	103.75	5.76	380.76	0.38	0.10	45,69	3.807
Schotia brachypetala	20	427.76	21.39	1 569.88	1.57	0.41	188,39	15.70
Senegalia galpinii	41	751.50	18.33	2 758.02	2.76	0.72	330,96	27.58
Searsia lancea	379	17 176.64	45.32	63 038.27	63.04	16.59	7 564,59	630.38
Searsia pendulina	45	2 413.89	45.26	8 858.96	8.86	2.31	1 063,08	88.59
Vachellia karroo	3	144.04	48.01	528.63	0.53	0.14	63,44	5.29
Vachellia sieberiana var. *woodii*	20	15 86.41	79.32	5 822.13	5.82	1.5	698,66	58.22
Total	**2 498**	**103 526.36**	**33.17**	**379 941.72**	**379.94**	**100**	**45 593,01**	**3,799.42**

The total standing carbon stocks for the measured trees (n = 2 498) were 103 526.36 kg and 379.94 tCO_2 valued at R45 593,01 or US$3,799.42 in 2017. *C. africana* contributes the most (42%; 162.73 tCO_2), *C. erythrophyllum* the second most (26.80%; 101.85 tCO_2) and *S. lancea* the third most (16.59%; 63.04 tCO_2) to the standing carbon stock for all the trees. This is due to their high numbers in the sample size, which were n = 834, n = 732 and n = 379, respectively. Most of the sample trees in this study comprised these three species. The lowest contributions to the total standing carbon stocks for the trees measured were from *Podocarpus* spp. (0.10%; 0.38 tCO_2), *H. caffrum* (0.13%; 0.50 tCO_2) and *K. africana* (0.15%; 0.57 tCO_2). Even though low numbers of these trees were measured (18, 10 and 9, respectively), they are not the tree species with the lowest numbers measured. The tree species with the least trees measured (n = 3) was *V. karroo* which contributed 5.82 tCO_2 to the standing carbon stocks.

The mean carbon per tree species result provides a more suitable comparison. The tree species with the highest mean standing carbon stock per tree was *V. sieberiana* var. *woodii* (79.32 kg per tree) and the second highest was *C. africana* (53.17 kg per tree). Three tree species presented mean standing carbon stocks in the 40-50 kg range: *V. karroo* (48.01 kg per tree), *S. lancea* (45.94 kg per tree) and *S. pendulina* (45.26 kg per tree). Only *C. erythrophyllum* presented a mean standing carbon stock in the 30-40 kg range with 37.91 kg per tree and four species presented mean standing carbon stocks in the 20-30 kg range: *K. africana* (26.13 kg per tree), *S. brachypetala* (25.02 kg per tree), *A. falcatus* (22.36 kg per tree) and *O. europaea* subsp. *africana* (20.73 kg per tree). The tree species with the lowest mean standing carbon stock per tree were *S. galpinii* (18.33 kg per tree), *H. caffrum* (14.30 kg per tree) and *Podocarpus* spp. (5.76 kg per tree).

There was a difference between the results of the total carbon stocks and value for all the standing trees measured, per tree species, with a standard error of 2.49% (Table 6.2) and the results of the total carbon stocks and value of the measured trees, minus the trees with fewer than 20 trees measured as per standard error 2.06% (Table 6.3). The results with the standard error of 2.49% displayed the total standing carbon (n = 2 498) as 103 526.36 kg, the standing CO_2 in kg as 379 941.72 kg, the CO_2 in tons as 379.94 tCO_2, the ZAR value as R45 593,01 and the US$ value for the CO_2 as US$3,799.42. The results with the standard error of 2.06% presented the total standing carbon (n = 2 458) as 102 985.83 kg, the standing CO_2 in kg as 377 957.98 kg, the CO_2 in tons as 37 796.94 tCO_2, the ZAR value as R45 354,96 and the US$ value for the CO_2 as US$3,779.57. Results are provided for each tree species indicating the number (n) per species, total standing carbon for the trees measured in kg, mean carbon per species in kg, the total CO_2 measured in kg and tCO_2, the tCO_2 percentage contribution and the respective value in South African rand and US dollars in Table 6.3, without the *Harpephyllym caffrum*, *Kiggelaria africana*, *Podocarpus* spp. and *Vachellia karee* species.

Table 6.3: Total standing carbon stocks of each tree species (SE 2.06%) without Harpephyllum caffrum, Kiggelaria africana, Podocarpus spp. and *Vachellia karroo*

Tree species	n	Total standing carbon stocks (kg)	Mean carbon (kg)	Total CO_2 (kg)	Total CO_2 (tCO_2)	% tCO_2	ZAR	US$
Afrocarpus falcatus	40	894.41	22.36	3282.50	3.28	0.86	393,90	32.80
Celtis africana	834	44 341.29	53.17	162 732.53	162.73	43.05	19 527,90	1,627.30
Combretum erythrophyllum	732	25 687.73	37.91	101 846.65	101.84	26.9	12 221,60	1,018.40
Harpephyllum caffrum	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Kiggelaria africana	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Olea europaea subsp. *africana*	347	7 193.45	20.73	28 049.04	28.05	7.42	3 365,88	280.50
Podocarpus spp.	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Schotia brachypetala	20	500.34	25.02	1 569.88	1.57	0.41	188,39	15.70
Senegalia galpinii	41	751.50	18.33	2 758.02	2.76	0.73	330,96	27.60
Searsia lancea	379	17 410.37	45.94	63 038.27	63.03	16.67	7 564,59	630.3
Searsia pendulina	45	2 036.81	45.26	8 858.96	8.85	2.31	1 063,08	88.50
Vachellia karroo	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Vachellia sieberiana var. *woodii*	20	1 586.41	79.32	5 822.13	5.82	3.77	698,66	58.20
Total	**2 458**	**102 985.83**	**348.04**	**377 957.98**	**377.95**	**100**	**45 354,96**	**3,779.57**

The difference in the results was due to the 40 trees (n = 2 498 minus n = 2 458) not forming part of the results (where the species with fewer than 20 trees measured were removed). When the results of the SE 2.49% are related to the SE 2.06%, the difference in the total standing carbon stocks is 540.53 kg, the difference in the standing CO_2 is 1 983.74 kg, the difference in the CO_2 in tons is 1.98 tCO_2 and the difference in the value for the CO_2 is R238,05 and US$19.85. This equates to a difference of 0.52%, which is a very low percentage difference and therefore, SE 2.49% was an acceptable standard error for this study. Therefore, trees with fewer than 20 in the sample provided an acceptable standard error and the total number of tree species measured is used to report the remainder of the results at an SE of 2.49%.

In summary, the total standing carbon stocks for the measured trees (n = 2 498) were 103 526.36 kg and 379.94 tCO_2 valued at R45 593,01 or US$3,799.42. *Celtis africana* contributed the most standing carbon stock and CO_2, *C. erythrophyllum* the second most and *S. lancea* the third most to the project, due to their high numbers. However, the tree species with the highest mean per tree was *V. sieberiana* var. *woodii* (79.32 kg per tree), the second highest mean per tree was *C. africana* (53.17 kg per tree) and the third highest mean total standing carbon stock was *V. karroo* (48.01 kg per tree). The tree species with the lowest mean per tree were *S. galpinii* (18.33 kg per tree), *H. caffrum* (14.30 kg per tree) and *Podocarpus* spp. (5.76 kg per tree).

6.3.2 Standing carbon for each region

The standing carbon for each region is presented with the aim to identify the carbon stocks of each region. The results are presented for the measured trees (n = 2 498) in this study. In each of the tables below (Tables 6.4 to 6.8) the tree species, number of trees measured, total carbon for the measured trees in kg, mean total carbon per tree species in kg, total CO_2 in kg for the measured trees, total CO_2 in tons, the tCO_2 percentage contribution for the standing trees, ZAR for the CO_2 (National Treasury) and US$ for the CO_2 based on a hypothetical estimation are presented. The total standing CO_2 in tCO_2 and its respective value in ZAR will be reported as it is used to determine the value of the carbon.

6.3.2.1 Region A

The locations of the trees in Region A are indicated in Figure 6.2.

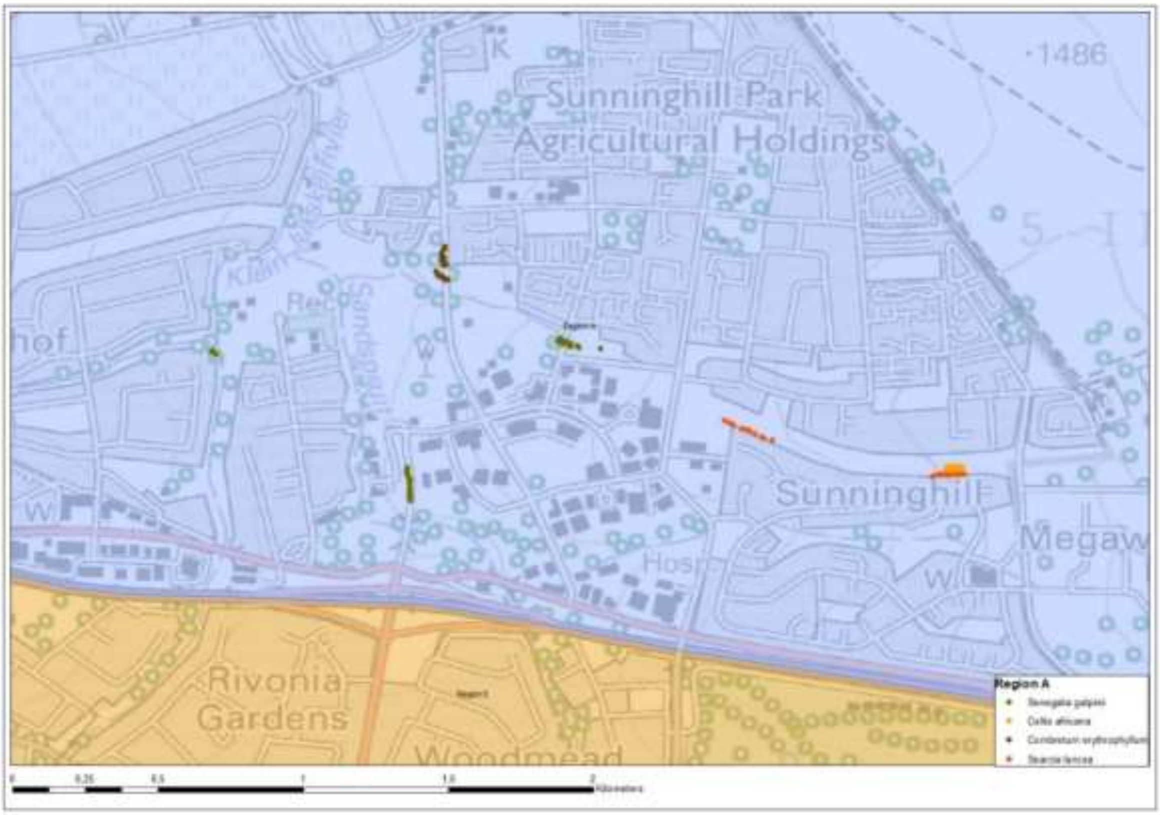


Figure 6.2: Individual trees in Region A in different colours

Results for Region A (n = 114) are presented in Table 6.4, showing the total standing CO_2 (7.634 tCO_2) of the region valued at R915,93. The tree species with the highest standing CO_2 (2.76 tCO_2; 36.15%) and value (R330,96) was *S. galpinii* with the highest numbers measured in the region. The tree species with the lowest standing CO_2 (0.004 tCO_2; 0.50%) and value of R0,50 was *S. pendulina*. Only one *S. pendulina* tree was measured in the region.

Table 6.4: Total standing carbon stocks and value of trees in Region A

Tree species	n	Total standing carbon stocks (kg)	Mean carbon (kg)	Total CO_2 (kg)	Total CO_2 (tCO_2)	% tCO_2	ZAR	US$
Afrocarpus falcatus	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Celtis africana	21	414.35	19.73	1 520.66	1.52	19.91	182,48	15.21
Combretum erythrophyllum	26	172.35	6.63	632.52	0.63	8.25	75,90	6.33
Harpephyllum caffrum	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Kiggelaria africana	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Olea europaea subsp. *africana*	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Podocarpus spp.	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Schotia brachypetala	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Senegalia galpinii	41	751.50	18.33	2 758.01	2.76	36.15	330,96	27.58
Searsia lancea	25	740.43	29.62	2 717.38	2.72	35.63	326,09	27.17
Searsia pendulina	1	1.13	1.13	4.15	0.004	0.05	0,50	0.04
Vachellia karroo	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Vachellia sieberiana var. *woodii*	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Total	**114**	**2 079.76**	**18.24**	**7 632.72**	**7.634**	**100**	**915,93**	**76.33**

6.3.2.2 Region B

The smallest number of trees (n = 63) was measured in Region B (Figure 6.3). Results are indicated in Table 6.5 where the species with the highest standing CO_2 (1.64 tCO_2) and the highest value (R196,62/US$16.39) was *C. erythrophyllum* (n = 36) and contributed the most (58.36%) to the standing carbon in the region. Only nine *C. africana* trees were measured in the region, resulting in total standing CO_2 (0.79 tCO_2) valued at R94,46 and US$7.87. The total standing CO_2 (2.81 tCO_2) for the region is valued at R336,77/US$28.06.

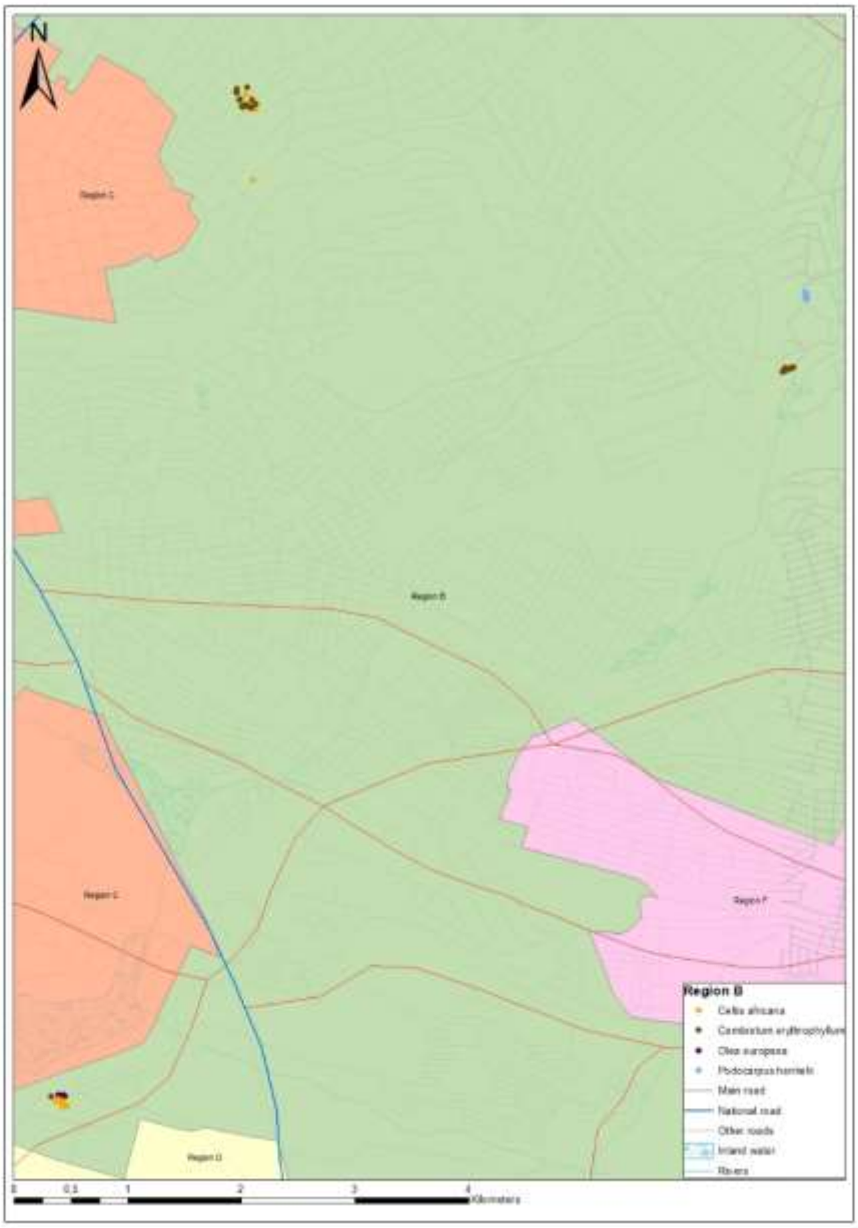


Figure 6.3: Map of Region B with the measured trees per species

Table 6.5: Total standing carbon stocks and value of trees in Region B

Tree species	n	Total standing carbon stocks (kg)	Mean carbon (kg)	Total CO_2 (kg)	Total CO_2 (tCO_2)	% tCO_2	ZAR	US$
Afrocarpus falcatus	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Celtis africana	9	214.49	23.83	787.16	0.79	28.11	94,46	0.00
Combretum erythrophyllum	36	446.46	12.40	1 638.52	1.64	58.36	196,62	0.00
Harpephyllum caffrum	0	0.00	0.00	0.00	0.00	0	0,00	7.87
Kiggelaria africana	0	0.00	0.00	0.00	0.00	0	0,00	16.39
Olea europaea subsp. *africana*	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Podocarpus spp.	18	103.75	5.76	380.76	0.38	13.52	45,69	0.00
Schotia brachypetala	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Senegalia galpinii	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Searsia lancea	0	0.00	0.00	0.00	0.00	0	0,00	3.81
Searsia pendulina	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Vachellia karroo	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Vachellia sieberiana var. *woodii*	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Total	**63**	**764.70**	**12.14**	**2 806.45**	**2.81**	**100**	**336,77**	**28.06**

6.3.2.3 Region C

The locations of the 832 trees measured in the region are visible on the map in Figure 6.4. The results for the standing carbon stocks for Region C are presented in Table 6.6 and indicate that the total standing CO_2 (122.89 tCO_2) for the region is valued at R14 746,55 and US$1,228.88. The species with the highest standing CO_2 was *C. erythrophyllum* (n = 282) (35.08 tCO_2) valued at R4 210,09/US$391.72 and contributed the most (31.87%) to the standing carbon in this region. The species with the lowest standing CO_2 was *H. caffrum* (0.52 tCO_2) valued at R62,97/US$5.25 and contributing 0.42% of the carbon in the region.

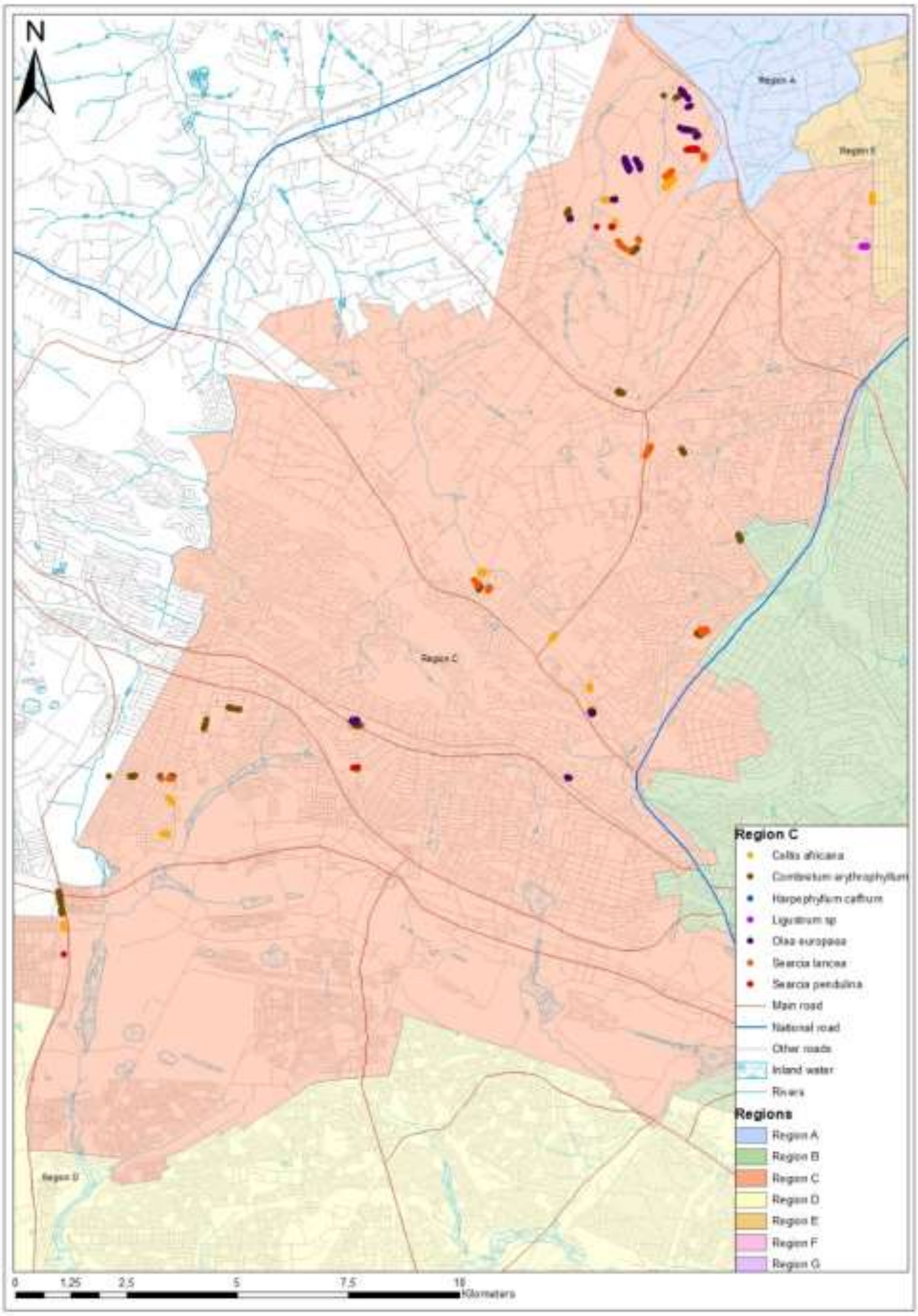


Figure 6.4: Map of measured trees in Region C

Table 6.6: Total standing carbon stocks and value of trees in Region C

Tree species	n	Total standing carbon stocks (kg)	Mean carbon (kg)	Total CO_2 (kg)	Total CO_2 (tCO_2)	% tCO_2	ZAR	US$
Afrocarpus falcatus	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Celtis africana	231	9 559.69	41.383	35 084.06	35.08	28.54	4 210,09	350.84
Combretum erythrophyllum	282	10 673.65	37.849	39 172.30	39.17	31.87	4 700,68	391.72
Harpephyllum caffrum	10	142.98	14.30	524.74	0.52	0.42	62,97	5.25
Kiggelaria africana	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Olea europaea subsp. *africana*	162	4 981.29	30.75	18 281.33	18.28	14.87	2 193,76	182.81
Podocarpus spp.	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Schotia brachypetala	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Senegalia galpinii	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Searsia lancea	122	6 470.13	53.03	23 745.38	23.75	19.32	2 849,45	237.45
Searsia pendulina	25	1 656.71	66.27	6 080.13	6.08	4.95	729,62	60.80
Vachellia karroo	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Vachellia sieberiana var. *woodii*	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Total	**832**	**33 484.45**	**40.25**	**122 887.93**	**122.89**	**100**	**14 746,55**	**1,228.88**

6.3.2.4 Region D

The highest number (n = 1 280) of trees in this study were measured in Region D (Figure 6.5). Results are displayed in Table 6.7 and indicate that the standing CO_2 (205.28 tCO_2) for Region D had a value of R24 633,38/US$2,052.78. The tree species with the highest numbers (n = 496) was *C. africana,* contributing 53.42% of the standing carbon in the region (109.66 tCO_2), valued at R13 159,78/US$1,096.65.

Only one *V. karroo* was measured in the region, contributing 0.001% of the carbon in the region. The standing CO_2 (0.003 tCO_2) of *V. karroo* was valued at R0,43/US$0.03.

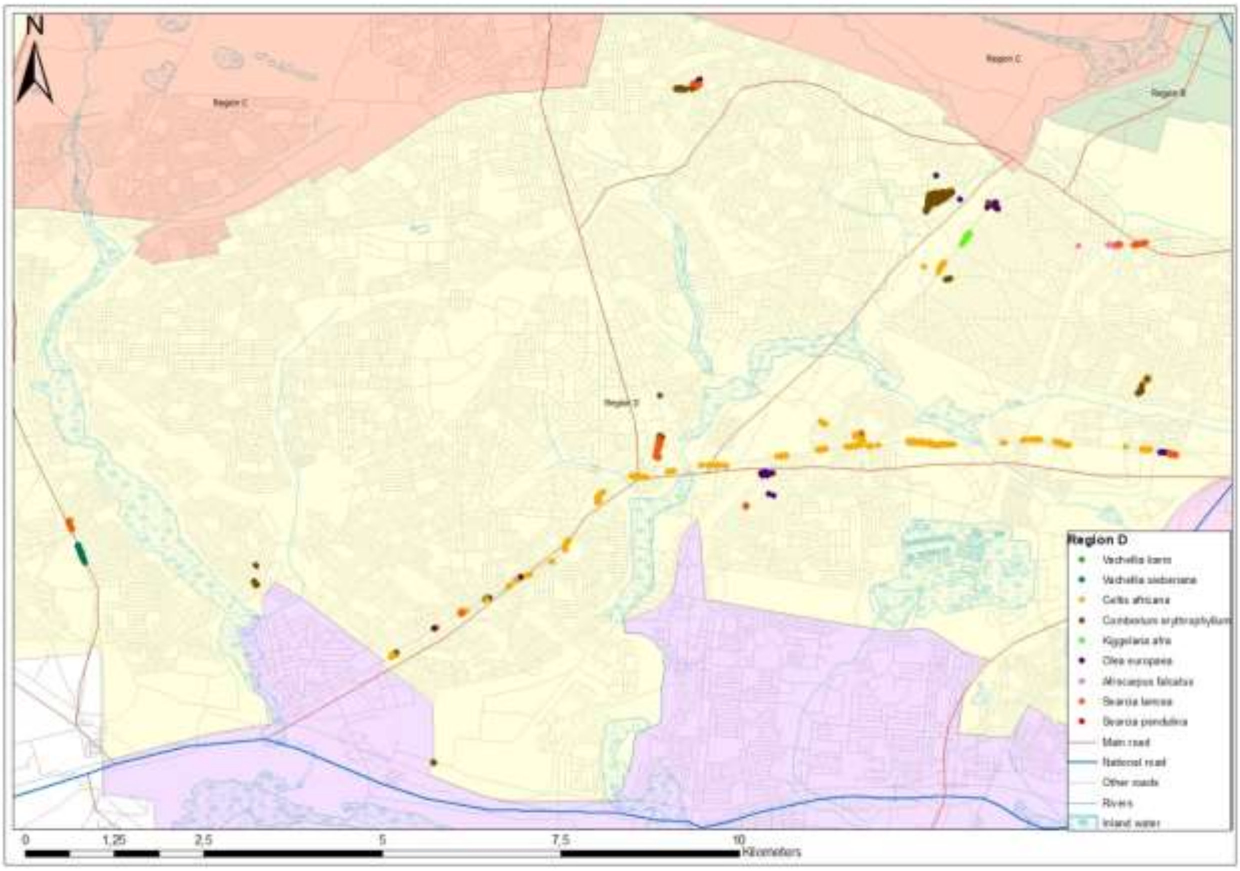


Figure 6.5: Locations of trees measured in Region D

Table 6.7: Total standing carbon stocks and value of trees in Region D

Tree species	n	Total standing carbon stocks (kg)	Mean carbon (kg)	Total CO_2 (kg)	Total CO_2 (tCO_2)	tCO_2	ZAR	US$
Afrocarpus falcatus	20	262.85	13.14	964.65	0.96	0.47	115,75	9.65
Celtis africana	496	29 881.43	60.24	109 664.85	109.66	53.42	13 159,78	1,096.65
Combretum erythrophyllum	348	12 290.32	35.32	45 105.47	45.10	21.96	5 412,65	451.05
Harpephyllum caffrum	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Kiggelaria africana	9	172.78	19.20	634.10	0.63	0.30	76,09	6.34
Olea europaea subsp. *africana*	165	2 493.72	15.11	9 151.95	9.15	4.45	1 098,23	91.52
Podocarpus spp.	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Schotia brachypetala	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Senegalia galpinii	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Searsia lancea	204	8 491.05	41.62	31 162.15	31.16	15.17	3 739,46	311.62
Searsia pendulina	17	754.57	44.39	2 769.27	2.77	1.35	332,31	27.69
Vachellia karroo	1	0.971	0.97	3.56	0.003	0.001	0,43	0.04
Vachellia sieberiana var. *woodii*	20	1 586.41	79.32	5 822.12	5.82	2.83	698,65	58.22
Total	**1280**	**55 934.13**	**43.70**	**205 278.27**	**205.28**	**100**	**24 633,38**	**2,052.78**

6.3.2.5 Region F

The total number of trees in Region F (n = 209) is seen in Figure 6.6. The results for Region F are depicted in Table 6.8 and indicate that the total standing CO_2 (41.34 tCO_2) for the region is valued at R4 960,36/US$413.36. The tree species with the highest standing CO_2 (15.89 tCO_2), valued at R1 906,85/US$158.90 was *C. africana* (n = 79), contributing 38.43% to the standing carbon in the region. Due to only two *V. karroo* trees measured in the region, with the total standing CO_2 (0.53t CO_2), valued at R63,01/US$5.25, this species contributed the least (1.28%) to the standing carbon in the region.

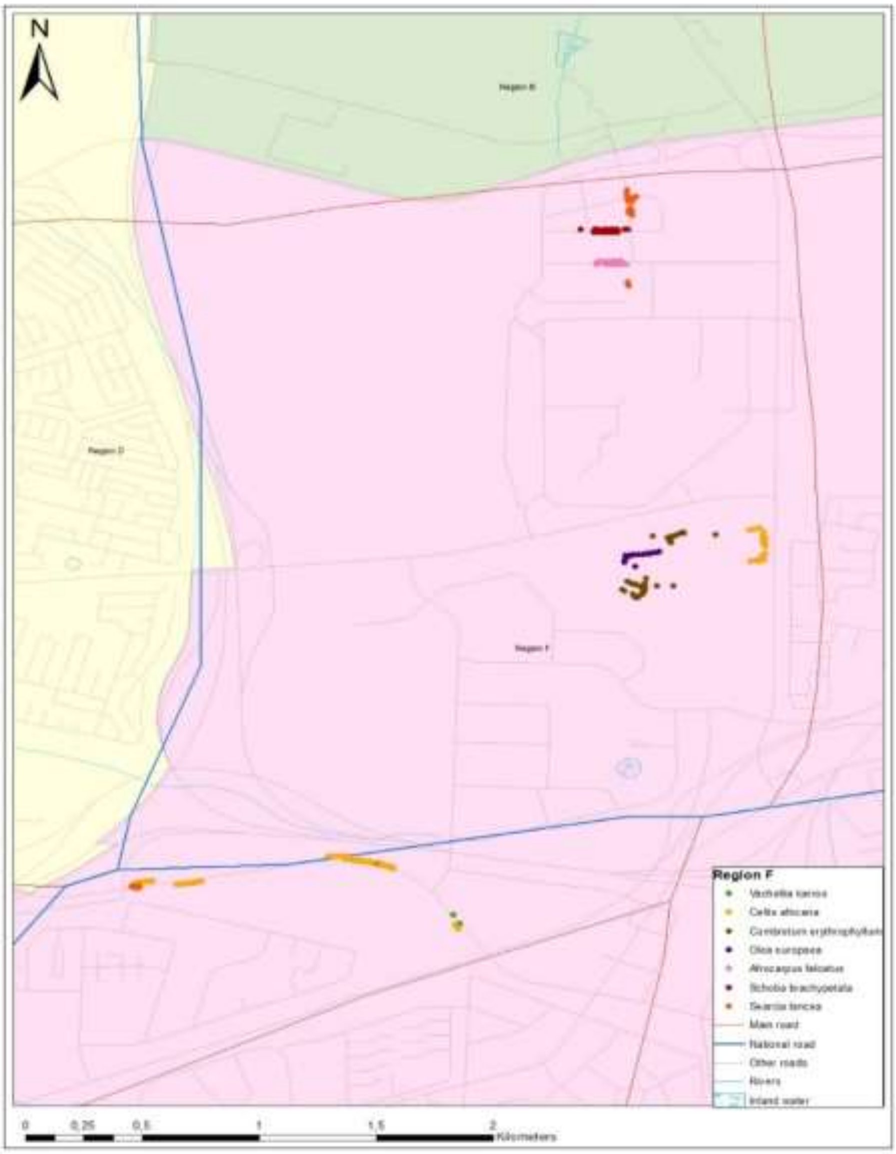


Figure 6.6: Location of trees measured in Region F

Table 6.8: Total standing carbon stocks and value of trees in Region F

Tree species	n	Total standing carbon stocks (kg)	Mean carbon (kg)	Total CO_2 (kg)	Total CO_2 (tCO_2)	tCO_2	ZAR	US$
Afrocarpus falcatus	20	631.57	31.58	2 317.86	2.32	5.61	278,14	23.18
Celtis africana	79	4 329.81	54.81	15 890.40	15.89	38.43	1 906,85	158.90
Combretum erythrophyllum	40	4 169.78	104.24	15 303.09	15.30	37.01	1 836,37	153.03
Harpephyllum caffrum	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Kiggelaria africana	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Olea europaea subsp. *africana*	20	167.78	8.39	615.75	0.62	1.50	73,89	6.16
Podocarpus spp.	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Schotia brachypetala	20	427.75	21.39	1 569.84	1.57	3.79	188,38	15.70
Senegalia galpinii	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Searsia lancea	28	1 393.56	49.77	5 114.37	5.11	12.36	613,72	51.14
Searsia pendulina	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Vachellia karroo	2	143.065	71.53	525.05	0.53	1.28	63,01	5.25
Vachellia sieberiana var. *woodii*	0	0.00	0.00	0.00	0.00	0	0,00	0.00
Total	**209**	**11 263.32**	**53.89**	**41 336.37**	**41.34**	**100**	**4 960,36**	**413.36**

6.3.2.6 Standing carbon for all the regions in the study

The results of the total standing carbon stocks for all the measured trees (n = 2 498) in the regions in this study are presented in Table 6.9. The total standing carbon stocks (103 526.4 kg) and the total standing CO_2 (379.94tCO_2) were valued at R45 593,01/US$3, 799.50. The totals of these results were the same as the results for all the tree species in this study, as seen in Table 6.2.

The results show that most of the total standing CO_2 was found in Region D (54.03% or 205.28 tCO_2) and the least was found in Region B (0.74% or 2.81 tCO_2), also seen in Table 6.9. This is due to the difference in numbers of trees where n = 1 280 were measured in Region D compared with n = 63 in Region B. Most of the data was collected in Regions

C and D (n = 832 and n = 1 208, respectively) and delivered 86.37% or 328.17 tCO_2 of the total standing CO_2 in this study. Regions A, B and F contributed 13.62% or 51.78 tCO_2 of the standing CO_2 stock of the measured trees.

Table 6.9: Summary of total standing carbon stock per region

Region	n	% trees /region	Total standing carbon stocks (kg)	Mean carbon (kg)	Total CO_2 (kg)	Total CO_2 (tCO_2)	% tCO_2	ZAR	US$
REGION A	114	4.56	2 079.76	18.24	7 632.72	7.63	2.01	915,93	76.30
REGION B	63	2.52	764.70	12.12	2 806.45	2.81	0.74	336,78	28.10
REGION C	832	33.31	33 484.45	40.25	122 887.93	122.89	32.34	14 746,55	1,228.90
REGION D	1280	51.24	55 934.13	43.70	205 278.27	205.28	54.03	24 633,38	2,052.80
REGION F	209	8.37	11 263.32	53.89	413 36.37	41.34	10.87	4 960,36	413.40
TOTAL	**2498**	**100**	**103 526.4**	**33.64**	**379 941.7**	**379.95**	**100**	**45 592,99**	**3,799.50**

However, the percentage distribution of the trees does not correlate with the percentage distribution of the total standing CO_2 per region. Region A contributed 2.01% of the standing CO_2 of the study but had 4.56% of the trees, Region B contributed 0.74% of the standing CO_2 but had 2.52% of the trees, Region C contributed 32.34% of the standing CO_2 and had 32.34% of the trees, Region D contributed 54.03% of the standing CO_2 but had 51.24% of the trees and Region F contributed 10.87% of the standing CO_2 but had 8.37% of the trees. Therefore, the reasons for the distribution of the standing CO_2 cannot be attributed only to the difference in the number of trees per region.

6.3.3 Tree circumference measurements

To identify reasons for the differences in the total standing CO_2 relative to the number of measured trees in the different regions, the tree circumference measurements of this study were considered. The circumference measurement of each tree was used to determine the quantity of carbon sequestered by the tree and therefore, the maximum and minimum circumference of the individual tree species provided the data necessary to interpret the standing carbon results. As discussed previously, the circumference was measured at 50 mm from the base of the tree and is referred to as CGL.

The results are provided as means for each individual tree species (Table 6.10) and as means for each tree species, per region (Table 6.11). Due to the difference in the sample numbers of the tree species, the data of the total standing carbon stock of these species cannot be compared with each other. Therefore, the means per tree species were calculated to enable comparisons of the standing carbon stocks per tree species across the different regions (Table 6.10).

Table 6.10: Maximum, minimum and mean CGL measurements per tree species

Tree species	Number of trees	% trees	Minimum circumference (mm)	Maximum circumference (mm)	Mean circumference (mm)
Afrocarpus falcatus	40	1.6	267	605	413
Celtis africana	834	33.38	35	1 259	359
Combretum erythrophyllum	732	29.38	55	1 557	449
Harpephyllum caffrum	10	0.40	245	483	338
Kiggelaria africana	9	0.36	314	656	444
Olea europaea subsp. *africana*	347	13.89	113	897	373
Podocarpus spp.	18	0.72	117	315	236
Schotia brachypetala	20	0.80	169	531	344
Senegalia galpinii	41	1.64	137	632	362
Searsia lancea	379	15.17	117	1 336	526
Searsia pendulina	45	1.80	99	1 048	497
Vachellia karroo	3	0.12	116	914	427
Vachellia sieberiana var. *woodii*	20	0.80	400	1 025	667

n = 2 498

As seen in Table 6.10, the tree species with the widest maximum circumference measurement are *C. erythrophyllum* (1 557 mm), followed by *S. lancea* (1 336 mm) and *C. africana* (1 259 mm). *S. pendulina* (1 048 mm) and *V. sieberiana* var. *woodii* (1 025 mm) also had a maximum CGL measurement wider than 1 m. As mentioned before, the trees with circumference measurements wider than 1 m may have been due to these trees being larger at planting than specified, as a 1 m circumference is considered to be too wide for the period of growth of the trees in this study. During the field survey these trees were detected in the same row of sample trees and were therefore captured as part of the study. The tree species with the smallest maximum circumference were *Podocarpus* spp. (315 mm) and thereafter *H. caffrum* (483 mm). The tree species with the widest minimum CGL measurement is *V. sieberiana* var.

woodii (400 mm), followed by *K. africana* (314 mm) and *A. falcatus* (267 mm). The tree species with the smallest minimum CGL measurement was *C. africana* (35 mm), followed by *C. erythrophyllum* (55 mm) as the second smallest and *S. pendulina* (99 mm) as the third smallest.

The maximum, minimum and mean circumferences for each tree species, for each region, are shown in Table 6.11. The results are discussed per region and the differences in these measurements for the trees in these regions are highlighted.

These results confirm the findings in the previous chapter that a range of tree sizes (circumference measurements) was found across the tree species and across regions.

Region A contributed 2.01% of the standing CO_2 of the study but had 4.56% of the trees. The circumference measurements of the trees in this region were smaller than most of the other regions. *C. africana* (525 mm), *C. erythrophyllum* (484 mm), *S. lancea* (653 mm) and *S. pendulina* (175 mm) trees in the region had the smallest maximum circumference measurement of all the regions. The mean circumference measurements of *C. erythrophyllum* (229 mm) and *S. lancea* (467 mm) were the smallest of all the regions. These measurements indicate that smaller trees were found in this region.

Region B stored the least standing carbon of all the regions (0.74%) but had 2.52% of the trees. The circumference measurement of *C. africana* in this region had the lowest mean (174 mm) of all the *C. africana* trees. The *Podocarpus* spp. found only in this region were smaller than most of the other species in this study. The maximum circumference of this species (315 mm), minimum circumference (117 mm) and mean circumference (236 mm) confirm that these were small trees.

Region C contributed 32.34% of the standing CO_2 with 33.31% of the trees. The *C. erythrophyllum* species contributed the most to the standing carbon in the region and the trees from this species with the widest maximum circumference in the study (1 557 mm) was found in this region. The *C. africana* trees in the region had the second widest maximum circumference (1 125 mm) in the study. As mentioned before, trees with circumference measurements wider than 1 m may have been due to these trees being larger than specified at the date of planting.

Table 6.11: Maximum, minimum and mean CGL measurements in mm per region

Tree species	% trees	Circ.	Region A (mm)	Region B (mm)	Region C (mm)	Region D (mm)	Region F (mm)
Afrocarpus falcatus	1.6	MAX	0	0	0	500	605
		MIN	0	0	0	267	351
		MEAN	0	0	0	338	488
Celtis africana	33.38	MAX	525	563	1 125	1 345	1 345
		MIN	124	250	46	85	437
		MEAN	373	174	468	585	718
Combretum erythrophyllum	29.38	MAX	484	605	1 557	1 405	1 105
		MIN	75	124	55	120	282
		MEAN	229	310	447	379	558
Harpephyllum caffrum	0.40	MAX	0	0	483	0	0
		MIN	0	0	245	0	0
		MEAN	0	0	338	0	0
Kiggelaria africana	0.36	MAX	0	0	0	656	0
		MIN	0	0	0	314	0
		MEAN	0	0	0	444	0
Olea europaea subsp. *africana*	13.89	MAX	0	0	891	770	390
		MIN	0	0	133	113	180
		MEAN	0	0	461	297	275
Podocarpus spp.	0.72	MAX	0	315	0	0	0
		MIN	0	117	0	0	0
		MEAN	0	236	0	0	0
Schotia brachypetala	0.80	MAX	0	0	0	0	531
		MIN	0	0	0	0	169
		MEAN	0	0	0	0	344
Senegalia galpinii	1.64	MAX	632	0	0	0	0
		MIN	137	0	0	0	0
		MEAN	362	0	0	0	0
Searsia lancea	15.17	MAX	653	0	1 001	1 230	1 336
		MIN	290	0	216	117	339
		MEAN	467	0	574	509	596
Searsia pendulina	1.80	MAX	175	0	1 048	640	0
		MIN	175	0	99	270	0
		MEAN	175	0	523	438	0
Vachellia karroo	0.12	MAX	0	0	0	116	914
		MIN	0	0	0	116	251
		MEAN	0	0	0	116	583
Vachellia sieberiana var. *Woodii*	0.80	MAX	0	0	0	400	0
		MIN	0	0	0	1 025	0
		MEAN	0	0	0	667	0

The *O. europaea* subsp. *africana* and *S. pendulina* species in Region C had the widest maximum circumference measurement (891 mm and 1 048 mm, respectively) and the widest mean circumference measurement (461 mm and 523 mm, respectively) of these species in all the regions. However, the *S. lancea* trees in this region had the second smallest maximum circumference measurement, even though it was 1 001 mm, and the second smallest minimum circumference (216 mm) but the second widest mean circumference measurement (574 mm).

Similarly, Region D stored the most standing carbon and contributed 54.03% of the CO_2 and had 51.24% of the trees. *C. africana* in the region had the widest maximum circumference (1 345 mm) in the study, as did *C. erythrophyllum* (1 405 mm). This region was the only region where *K. africana* and *V. sieberiana* var*. woodii* were found and one of two regions where *A. falcatus* and *V. karroo* were found.

Region F contributed 10.87% of the standing CO_2 of the study but had 8.37% of the trees. The mean standing carbon stocks for Region F were the highest (53.89 kg/tree) and this region had the widest mean circumference measurements for most of the trees - *A. falcatus* (488 mm), *C. africana* (718 mm), *C. erythrophyllum* (558 mm), *S. lancea* (596 mm) and *V. karroo* (583 mm). This implies that the trees in this region were overall larger than the trees in other regions, resulting in a higher percentage standing CO_2 compared to the percentage of trees found in the region.

Regions contribute a lesser percentage to the standing CO_2 than the percentage of trees found in the regions due to the circumference measurements of these trees. These measurements indicate that Regions A and B had smaller trees or trees with a smaller circumference than the other regions and Region F had trees with wider circumference measurements than the other regions.

6.3.4 Standing carbon for the different years of planting

The results for the total standing carbon for the measured trees in this study and the regions combined for the different years of planting (Table 6.12) are presented in total standing carbon. Most of the standing carbon stocks (36.3% or 37 587.83 kg) were found in the trees planted during 2005, and the trees planted during 2010 provided the least carbon stocks (2.7% or 2 837.99 kg). The trees planted in 2005 (n = 661) should be the oldest and therefore have the most carbon. Fewer trees were planted (n = 172) in 2010 than in 2005 and they were 5 years younger. The mean carbon stock (56.87 kg) per tree for the trees planted in 2005 is the highest, and the mean carbon stock (16.50 kg) per tree for the trees planted in 2010 is the lowest. The standing carbon stocks are 36.3% of the total standing carbon for 2005, 23.93% for 2007 and 24.24% for 2008. The carbon stock is 9.8% for 2009, 3.9% for 2006 and 2.7%

for 2010. Most of the trees were planted in 2007 (n = 693), followed by 2005 (n = 661) and the least number of trees were planted in 2006 (n = 116) (Table 6.12).

The mean carbon stock per tree for 2008 (47.85 kg) with 503 trees planted was higher than that per tree for 2007 (35.75 kg) with 693 trees planted. The mean carbon stock per tree for 2008 (47.85 kg) and 2005 (56.87 kg) was higher than that per tree for the entire project (41.44 kg) and the mean carbon stocks for all the other years were lower. The mean carbon stock per tree for 2006 (35.24 kg) and 2007 (35.75 kg) was similar, but in 2007 there were 693 trees planted and in 2007 only 116 trees were planted (Table 6.12).

Table 6.12: Total standing carbon stocks per region, combined for the different years of planting

Regions	n	2005 kgC	2006 kgC	2007 kgC	2008 kgC	2009 kgC	2010 kgC	Totals
Region A	114	0	0	151.89	0	0	1 927.88	2 079.76
Region B	63	0	0	412.44	114.40	237.86	0	764.70
Region C	832	319.90	1 983.99	8 320.76	16 064.87	6 099.24	695.68	33 484.45
Region D	1 280	32 668.06	2 103.44	15 890.42	3 353.03	1 704.74	214.42	55 934.13
Region F	209	4 599.87	0	0	4 534.75	2 128.70	0	11 263.32
Totals		**37 587.83**	**4 087.43**	**24 775.51**	**24 067.04**	**10 170.55**	**2 837.99**	**103 526.36**
Number of trees	**2 498**	**661**	**116**	**693**	**503**	**353**	**172**	**2498**
Mean standing carbon		**56.87**	**35.24**	**35.75**	**47.85**	**27.71**	**16.50**	**41.44**

In summary, most of the standing carbon stocks were accumulated and stored by the trees planted during the first year of tree planting (2005) and the least were accumulated and stored by the trees planted during the last year (2010) of the project. The number of trees planted in 2005 is only the second highest, but the mean standing carbon stock per tree is the highest of all the years and that per tree for the trees planted during 2010 is the lowest.

6.3.5 Standing carbon for street and park trees

Results are presented for the measured (n = 2 498) trees in the study, divided into the planting locations, namely parks and streets, and streets are divided into sidewalks and medians, to identify which of these contributed the most standing carbon. The results for these locations are presented in Table 6.13. Most (67.9%; n = 1 698) of the trees were planted as street trees. Of the street trees, 18.7% (n = 319) were planted on medians and 81.2% (n = 1 379) on sidewalks. The trees planted in the streets contributed 269.56 tCO_2 of the standing carbon of the project, the median trees contributed 49.69 tCO_2 and the sidewalk trees 219.87 tCO_2. The remaining 32.5% (n = 814) of the trees were planted in parks and contributed 98.2 tCO_2 to the standing carbon.

The mean standing carbon stocks per tree for the trees in the medians and on the sidewalks were 0.16 tCO_2 per tree and those for the trees planted in the parks were 0.12 tCO_2. This indicates that the trees in the parks were smaller with a smaller CGL than the trees planted in the streets.

Table 6.13: Standing carbon and tree number of trees planted in streets, on sidewalks and medians and in parks

Tree species	Street/median			Street/sidewalk			Park			Total tCO_2	Total trees
	tCO_2	n	Mean per tree (tCO_2)	tCO_2	n	Mean per tree (tCO_2)	tCO_2	n	Mean per tree (tCO_2)		
Afrocarpus falcatus	0.96	20	0.48	2.32	20	0.12	0	0	0	3.28	40
Celtis africana	22.51	103	0.22	114.28	553	0.21	26.51	178	0.15	162.73	834
Combretum erythrophyllum	4.83	63	0.77	47.06	333	0.14	42.38	335	0.13	101.85	731
Harpephyllum caffrum	0	0	0	0.50	10	0.05	0	0	0	0.50	10
Kiggelaria africana	0.57	9	0.10	0	0	0	0	0	0	0.57	9
Olea europaea sub sp. africana	1.73	33	0.05	16.19	181	0.09	8.48	133	0.06	28.05	347
Podocarpus spp.	0	0	0	0	0	0	0.38	18	0.02	0.38	18
Schotia brachypetala	0	0	0	1.57	20	0.09	0	0	0	1.57	20
Senegalia galpinii	0	0	0	2.76	41	0.07	0	0	0	2.76	41
Searsia lancea	12.76	68	0.18	33.48	190	0.18	17.66	121	0.15	63.04	379
Searsia pendulina	0.34	1	0.34	1.71	19	0.09	2.79	25	0.12	8.86	45
Vachellia karroo	0.53	3	0.17	0	0	0	0	0	0	0.52	3
Vachellia sieberiana var. woodii	5.82	20	0.31	0	0	0	0	0	0	5.82	20
TOTAL	49.69	319	0.16	219.87	1379	0.16	98.20	814	0.12	379.94	2 498
Percentage trees	0	12.77%	0	0	55%	0	0	32.42 %	0	0	0

The years of planting in these different locations were taken into consideration to further explain the differences in circumference measurements and CO_2 quantities in the streets and parks. These results are presented in Table 6.14.

Table 6.14: Number of trees planted in streets, on sidewalks and medians and in parks for the different years of the project

Location	2005	2006	2007	2008	2009	2010	Total
Streets: median	272	36	5	20	50	0	383
Streets: sidewalk	389	80	104	420	216	101	1310
Parks	0	0	584	63	87	71	805
TOTAL	**661**	**116**	**693**	**503**	**353**	**172**	**2 498**

As previously indicated, most of the trees were planted in 2007 and the least number of trees were planted in 2006. No trees were planted in parks in 2005 and 2006, but 31.1% of the street trees were planted in 2005 and 2006. Most of the trees on the medians (70%; n = 272) were planted during 2005, most of the trees on the sidewalks (32.06%; n = 420) were planted during 2007 and most of the trees in the parks (72.54%; n = 584) were also planted during 2007. Therefore, it can be assumed that the trees in the streets, both on the medians and sidewalks, were larger than the trees in the parks as they had one to two years more time to grow and develop secondary thickening; hence the larger circumference measurements and total standing carbon.

In summary, most of the trees in the GSTP project were planted as street trees on sidewalks (55%; n = 1 379) and these trees accumulated and stored most of the total standing carbon (57.86%; 219.87 tCO_2) in this study. The least number of trees (12.77%; n = 319) were planted on the medians in streets and stored the least total standing carbon (13.07%; 49.69 tCO_2). Both the median and sidewalk trees had a larger mean standing carbon per tree (0.16 tCO_2/tree), which indicates that the trees in the streets had a wider mean circumference than those in parks (0.12 tCO_2/tree). Most of the trees on the medians (10.88%; n = 272) and the second most trees on the sidewalks (15.57%; n = 389) were planted during 2005, indicating that they were older than the park trees as none of the park trees were planted in either 2005 or 2006. Trees were only planted in parks between 2007 and 2010, resulting in a smaller mean circumference than the trees on sidewalks and medians.

6.3.6 Summary of standing carbon stock

The total standing carbon stocks for the measured trees (n = 2 498) were 103 526.36 kg and 379.94 tCO_2 valued at R45 593,01 or US$3,799.42 in 2017. *C. africana* (n = 834) contributed 42% of the total standing carbon, *C. erythrophyllum* (n = 732) contributed 26.8% and *S. lancea* (n = 379) 16.8% for this study. These three tree species contributed 85.6% of the total standing carbon for this study. However, the tree species with the highest mean carbon stock per tree was *V. sieberiana var. woodii* (79.32 kg/tree), the second highest mean was *C. africana* (53.17

kg/tree) and third was *V. karroo* (48.01 kg/tree), indicating that these trees were on average larger (wider circumference measurements) than the other tree species.

When comparing the regions with each other, Region C (n = 832) and Region D (n = 1 280) contributed 86.3% of the total standing carbon for this study with 84% of the trees in the study. Regions A (n = 114), B (n = 63) and F (n = 209) contributed 14% of the total standing carbon for this study but had 16% of the trees in the study. Therefore, the more trees in a region, the more the total standing carbon for the region, but the percentage distribution of the trees was not in direct correlation with the percentage distribution of the total standing CO_2 per region. Using the tree circumference measurements, it was identified that the regions contributing less to the standing CO_2 than their tree numbers had smaller trees or trees with a smaller circumference than the other regions. The region that contributed more to the standing CO_2 than its tree numbers had trees with wider circumference measurements than the other regions. The results confirm that the wider the circumference of the tree, the higher the carbon value of the tree.

Correlations between CGL and standing carbon stocks point to a very strong positive correlation between CGL and carbon stock. As the tree grows and the CGL increases, the carbon stock increases, indicating that CGL can be used to predict the carbon stock in trees.

Most of the trees in the GSTP project were planted as street trees on sidewalks (n = 1 379) and these trees accumulated and stored most of the total standing carbon (219.87 tCO_2) in this study. The least number of trees (n = 393) were planted on the medians in streets and stored the least total standing carbon (49.69 tCO_2). The median and sidewalk trees had the same mean standing carbon per tree, which was larger than the mean of the trees in parks. This indicates that the trees in the streets had a wider mean circumference than the park trees. The planting dates may have contributed to this difference as most of the trees in the streets were planted during 2005 and 2006. None of the park trees were planted in the same period, indicating that the street trees were mostly older than the park trees and thus explaining their smaller mean circumference.

6.4 Estimated standing carbon stocks and value of all project trees

In Chapter 4 of this thesis the number of trees that were verified by this study was used to extrapolate the number of trees for the entire project and estimations were made according to different scenarios to estimate the number of trees that might be alive or existing in 2017. Results for the standing carbon stocks are given for (a) the planted trees (n = 206 627) according to the JCPZ tree register and (b) the estimated existing trees (n = 89 644) alive in 2017. The estimated existing trees were determined by adopting the percentage (43.46%) of trees that were verified as existing in Region D during the field survey, to calculate the estimated existing trees from the planted trees (n = 206 627). Results are given for each tree species indicating the number (n) per species, standing carbon for the planted trees measured in kg, the CO_2 measured in tCO_2 and the value in South African rand and US dollars. The carbon value is presented as a carbon tax value of ZAR120 per metric ton of CO_2, proposed by the National Treasury (Department of National Treasury, 2013) and a hypothetical estimation of US$10 per ton CO_2e.

6.4.1 Estimated standing carbon stocks for the planted trees on the JCPZ register

Results are displayed for the estimated standing carbon stocks for the planted trees (n = 206 267) on the JCPZ tree register in Table 6.15. The total standing carbon stocks for the trees planted in the GSTP project were 30 390.11 tCO_2 with a value of R3 646 812,87 or US$303,901.07.

Table 6.15: Standing carbon stocks for total number of planted trees

Tree species	Number of trees	Standing carbon (kg)	tCO_2	ZAR	US$
Afrocarpus falcatus	3 264	72 982.82	267.85	32 141,64	2,678.47
Celtis africana	62 795	3 338 645.16	12 252.83	1 470 339,33	122,528.28
Combretum erythrophyllum	62 015	2 176 260.10	7 986.87	958 424,95	79,868.75
Harpephyllum caffrum	710	10 144.90	37.23	4 467,81	372.32
Kiggelaria africana	993	25 954.10	95.25	11 430,19	952.52
Olea europaea subsp. *africana*	29 375	608 965.68	2 234.90	268 188,48	22,349.04
Podocarpus spp.	1 348	822 768	30.20	3 623,47	302.00
Schotia brachypetala	1 490	37 277.15	136.81	16 416,86	1,368.07
Senegalia galpinii	3 334	61 105.47	224.26	26 910,85	2,242.57
Searsia lancea	32 994	1 515 676.31	5 562.53	667 503,85	55,625.32
Searsia pendulina	6 457	292 256.23	1 072.58	128 709,64	10,725.80
Vachellia karroo	213	10 2203.40	37.51	4 501,06	375.09
Vachellia sieberiana var. *woodii*	1 632	129 448.95	475.08	57 009,32	4,750.78
Total	**206 267**	**8 280 683.17**	**30 390.11**	**3 646 812,87**	**303,901.07**

6.4.2 Estimated standing carbon stocks and value of estimated existing trees

Results for the estimated existing standing trees extrapolated to the entire project (n = 89 644) are depicted in Table 6.16. The total standing carbon stocks for the number of estimated existing trees still alive in 2017 were 13 207.59 tCO_2 valued at R1 584 911,27 or US$132,075.94.

Table 6.16: Standing carbon stocks for estimated existing trees

Tree species	Number of trees	Standing carbon (kg)	CO_2 (tCO_2)	ZAR	US$
Afrocarpus falcatus	1 419	31 718.46	116.41	13 968,81	1,164.07
Celtis africana	27 291	1 450 981.04	5 325.10	639 012,05	53,251.00
Combretum erythrophyllum	26 952	945 806.46	3 471.11	416 533,16	34,711.10
Harpephyllum caffrum	308	4 408.99	16.18	1 941,72	161.81
Kiggelaria africana	432	11 279.70	41.40	4 967,58	413.96
Olea europaea subsp. *africana*	12 767	264 657.55	971.29	116 555,19	9,712.93
Podocarpus spp.	586	3 575.77	13.12	1 574,77	131.23
Schotia brachypetala	648	16 200.72	59.46	7 134,80	594.57
Senegalia galpinii	1 295	23 739.54	87.12	10 454,89	871.24
Searsia lancea	14 339	658 715.58	2 417.49	290 098,34	24,174.86
Searsia pendulina	2 745	127 015.07	466.15	55 937,44	4,661.45
Vachellia karroo	93	4 441.80	16.30	1 956,17	163.01
Vachellia sieberiana var. *woodii*	709	56 258.74	206.47	24 776,35	2,064.70
Total	**89 644**	**3 598 799.43**	**13 207.59**	**1 584 911,27**	**132,075.94**

Therefore, the total standing carbon for all the trees planted in the GSTP project (n = 206 267), according to the JCPZ tree register, would have been 30 390.11 tCO_2 with a value of R3 646 812,87or US$303,901.07 if all the trees that were planted were alive in 2017. However, as seen in Chapter 4, some of the trees could not be verified as they had incorrect addresses, had died or were missing. It was estimated that the total standing carbon stocks of the estimated existing trees still alive in 2017 (n = 89 644) were 13 207.59 tCO_2 valued at R1 584 911,27 or US$132,075.94. The difference of 17 182.52 tCO_2 highlights the substantial loss in value of R2 061 901,60 or US$171,825.13, resulting in the project not contributing to the mitigation of climate change (Grace & Basso, 2012) as it could have if all the trees that were planted were alive in 2017.

6.4.3 Estimated standing carbon stocks of median, sidewalk and park trees extrapolated to scenarios a and b

The standing carbon stocks for the median, sidewalk and park trees were extrapolated to the (a) the planted trees (n = 206 267) on the JCPZ tree register and (b) the estimated existing trees alive in 2017 (n = 89 644). Results are provided for each tree species indicating the number (n) per species, standing carbon stocks in tCO_2 and the mean tCO_2 per species. The total tCO_2 is also provided for the extrapolated number of trees, per species, with the relevant percentage trees on the sidewalks and medians and in parks. The extrapolations are based on the mean tCO_2 of the measured trees, therefore depicting a slight difference in the amount of CO_2 when compared to the extrapolations seen in Tables 6.15 and 6.16.

The results for the planted trees on the tree register (n = 206 267) presented in Table 6.17 indicate that should the distribution of the trees be the same as the measured trees, the amount of CO_2 contributed by the median trees could have been 8 473 tCO_2, the sidewalk trees could have contributed 18 374 tCO_2 and the park trees 8 236 tCO_2.The results for the estimated existing trees alive in 2017 (n = 89 644) are presented in Table 6.18 and show that should the distribution of the trees be the same as the measured trees, the amount of CO_2 contributed by the median trees could have been 3 677 tCO_2, the sidewalk trees could have contributed 7 985 tCO_2 and the park trees 3 579 tCO_2.

Table 6.17: Total and mean standing carbon stock contributions of trees planted in streets/sidewalks, on medians and in parks extrapolated to n = 206 267

Tree species	Street/median			Street/sidewalk			Park			Total tCO_2	Total trees
	tCO_2	n	Mean per tree (tCO_2)	tCO_2	n	Mean per tree (tCO_2)	tCO_2	n	Mean per tree (tCO_2)		
Afrocarpus falcatus	793	1 651	0.48	198	1 651	0.12	0	0	0	991	3 264
Celtis africana	1 871	8 505	0.22	9 589	45 663	0.21	2 205	14 698	0.15	13 665	62 795
Combretum erythrophyllum	4 006	5 202	0.77	3 850	27 497	0.14	3 596	27 662	0.13	11 451	62 015
Harpephyllum caffrum	0	0	0	41	826	0.05	0	0	0	41	710
Kiggelaria africana	74	743	0.10	0	0	0	0	0	0	74	993
Olea europaea sub sp. africana	136	2 725	0.05	1 345	14 946	0.09	659	10 982	0.06	2 140	29 375
Podocarpus spp.	0	0	0	0	0	0	30	1 486	0.02	30	1 348
Schotia brachypetala	0	0	0	149	1 651	0.09	0	0	0	149	1 490
Senegalia galpinii	0	0	0	237	3 385	0.07	0	0	0	237	3 334
Searsia lancea	1 011	5 615	0.18	2 824	15 689	0.18	1 499	9 991	0.15	5 333	32 994
Searsia pendulina	28	83	0.34	141	1 569	0.09	248	2 064	0.12	417	6 457
Vachellia karroo	42	248	0.17	0	0	0	0	0	0	42	213
Vachellia sieberiana var. wo odii	512	1 651	0.31	0	0	0	0	0	0	512	1 632
TOTAL	8 473	**26 423**	0.16	18 374	**112 877**	0.16	8 236	**66 884**	0.12	35 083	**206 267**
Percentage trees	0	12.77%	0	0	55%	0	0	32.42 %	0	0	0

Table 6.18: Total standing carbon stock of estimated existing trees of GSTP planted in streets, on sidewalks and medians and in parks extrapolated to n = 89 644

Tree species	Street/median			Street/sidewalk			Park			Total tCO_2	Total trees
	tCO_2	n	Mean per tree	tCO_2	n	Mean per tree	tCO_2	n	Mean per tree		
Afrocarpus falcatus	345	709	0.48	86	709	0.12	0	0	0	431	1 419
Celtis africana	813	3 696	0.22	4 167	19 845	0.21	958	6 388	0.15	5 939	27 291
Combretum erythrophyllum	1 741	2 261	0.77	1 673	11 950	0.14	1563	12 022	0.13	4 977	26 952
Harpephyllum caffrum	0	0	0	18	359	0.05	0	0	0	18	308
Kiggelaria africana	32	323	0.10	0	0	0	0	0	0	32	432
Olea europaea sub sp. africana	59	1 184	0.05	585	6 495	0.09	286	4 773	0.06	930	12 767
Podocarpus spp.	0	0	0	0	0	0	13	646	0.02	13	586
Schotia brachypetala	0	0	0	65	718	0.09	0	0	0	65	648
Senegalia galpinii	0	0	0	103	1 471	0.07	0	0	0	103	1 295
Searsia lancea	439	2 440	0.18	1 227	6 818	0.18	651	4 342	0.15	2 318	14 399
Searsia pendulina	12	36	0.34	61	682	0.09	108	897	0.12	181	2 745
Vachellia karroo	16	93	0.17	0	0	0	0	0	0	16	93
Vachellia sieberiana var. wo odii	220	709	0.31	0	0	0	0	0	0	220	709
TOTAL	3 677	**11 460**	0.16	7 985	**49 057**	0.16	**3 579**	**29 068**	0.12	15 242	**89 644**
Percentage trees	0	12.77%	0	0	55%	0	0	32.42 %	0	0	0

Using the mean tCO_2 per tree and assuming that the distribution of the trees was the same as the measured trees, the median trees could have contributed 8 473 tCO_2, the sidewalk trees 18 374 tCO_2 and the park trees 8 236 tCO_2 to the carbon sink if the planted trees (n = 206 267) on the tree register were all still alive in 2017. However, it is estimated that the median trees could only contribute 3 677 tCO_2, the sidewalk trees 7 985 tCO_2 and the park trees 3 579 tCO_2 to the carbon if the estimated existing standing trees (n = 89 644) were still alive in 2017.

6.5 Estimated value of projected sequestered carbon stocks in 30 years

Growth rate relationships and carbon sequestration regression equations were used to calculate the estimated projected carbon sequestration of these trees (Stoffberg et al., 2010). Extrapolations were conducted for each tree species individually by applying the predictive table of Stoffberg (2006) and using the year of planting as the baseline. These calculations made it possible to estimate the future carbon sequestration value of the GSTP project over a period of 30 years.

As indicated previously, it is estimated that all the trees were 4 years old when they were planted, therefore the age of the trees was determined by adding 4 years to the planting date. This study was conducted in 2017; therefore, the trees planted in 2005 were 16 years old in 2017, projecting that they will be 30 years in 2031. The predictive table by Stoffberg (2006) provides estimations for a maximum of a 30-year period. The carbon estimations for the project are therefore calculated up to 2031. The trees planted in 2005 will have 30 years of growth by 2031 and will have accumulated 30 years of CO_2 stocks; the trees planted in 2006 will have 29 years of growth by 2031 and will have accumulated 29 years of CO_2 stocks, as expressed in Table 6.19. The youngest trees are the trees planted in 2010 and will have been growing for 25 years by 2031.

The estimated projected carbon sequestration of the trees planted in 2005 was determined by applying the mean confidence level estimation indicated in the predictive table for the specific species at 30 years. Similarly, the estimated projected carbon sequestration for the trees planted in other years was determined by applying the estimations as indicated in Table 6.19.

Table 6.19: Age of the trees in 2017 and in 2031

Year of planting	Age in 2017	Age in 2031
2005	16	30
2006	15	29
2007	14	28
2008	13	27
2009	12	26
2010	11	25

Results of the different years of planting for each tree species are presented in Table 6.20. The appropriate regression as indicated in the table was applied to the specific species. The number of trees per tree species as planted in each year was used to determine the projected percentage of trees per species, the projected sequestered CO_2 and the value of these trees in 2031.

Table 6.20: Regression models applied for the individual species in the study with the numbers of trees per year of planting

Species	**Regression model**	**Year of tree planting**						**Total trees**
		2005	2006	2007	2008	2009	2010	
Afrocarpus falcatus	*Searsia* species combined	40	0	0	0	0	0	40
Celtis africana	*C. erythrophyllum/ S. lancea* combined	278	112	206	108	81	49	834
Combretum erythrophyllum	*Combretum erythrophyllum*	36	41	297	196	162	16	732
Harpephyllum caffrum	*Searsia* species combined	0	0	0	10	0	0	10
Kiggelaria africana	*Searsia* species combined	0	0	0	9	0	0	9
Olea europaea subsp. africana	*Searsia* species combined	60	42	75	104	46	20	347
Podocarpus species	*Searsia* species combined	0	0	0	0	18	0	18
Schotia brachypetala	*Searsia* species combined	20	0	0	0	0	0	20
Senegalia galpinii	*C. erythrophyllum/ S. lancea* combined	0	0	0	0	0	41	41
Searsia lancea	*Searsia lancea*	85	40	110	75	48	21	379
Searsia pendulina	*Searsia* species combined	3	0	15	0	27	0	45
Vachellia karroo	*Searsia* species combined	3	0	0	0	0	0	3
Vachellia sieberiana var. woodii	*C. erythrophyllum/ S. lancea* combined	20	0	0	0	0	0	20
Total number of trees per year		545	235	703	502	382	147	2 498
Percentage distribution		21.4%	9.4%	28.1%	20.1%	15.3%	5.7%	100%

The sequestered carbon stocks were calculated individually for each species per year of planting. The results of the projected carbon (CO_2) and value for each year of planting were subsequently added together to produce the results for each scenario extrapolated to 2031. Results are presented for the number of trees, the mean confidence level (CL) of the total sequestered carbon stocks (kg), tCO_2 and the value (ZAR and US$) for the tCO_2, for each of the scenarios. Results are displayed for the projected sequestered carbon stocks for the measured trees in the study in Table 6.21.

Table 6.21: Sequestered carbon value for measured trees per species in 30 years (2031)

Tree species	Number of trees	Sequestered carbon (kg)	Sequestered tCO_2	ZAR	US$
Afrocarpus falcatus	40	10 774.00	39.54	4 745,05	395.42
Celtis africana	834	435 220.06	1 339.38	160 726,30	13,226.17
Combretum erythrophyllum	732	1 138 433.33	2 482.65	297 918,50	24,651.78
Harpephyllum caffrum	10	8 694.23	8.69	1 043,31	86.94
Kiggelaria africana	9	7 824.80	7.82	938,98	78.25
Olea europaea subsp. *africana*	347	150 723.60	311.73	37 408,11	3,087.33
Podocarpus spp.	18	4 069.08	14.93	1 792,02	149.33
Schotia brachypetala	20	5 387.20	19.77	2 372,52	197.71
Senegalia galpinii	41	15 858.39	58.20	6 984,03	441.69
Searsia lancea	379	145 018.09	353.14	42 376,68	3,491.76
Searsia pendulina	45	10 627.65	39.00	4 680,42	390.03
Vachellia karroo	3	808.08	2.96	355,88	29.65
Vachellia sieberiana var. *woodii*	20	10 020.60	36.77	4 413,07	367.75
Total	**2 498**	**1 943 459.52**	**4 714.63**	**565 755,00**	**46,593.84**

n = 2 498

It is estimated that in 2031, the measured trees of the GSTP project will have accumulated 4 714.63 tCO_2 valued at R565 755 and US$46,593.84. Most of the carbon will be stored by *C. erythrophyllum* (24651.78 tCO_2), and *V. karroo* (2.96 tCO_2) will contribute the least.

6.5.1 Projected sequestered carbon stocks and value estimations for different scenarios in 2031

Different scenarios of the number of trees estimated to be alive and growing in 2031 were identified in Chapter 4. These different scenarios were adapted to illustrate how the value of the GSTP project was influenced by different estimated survival rates of the trees.

Results are presented for these different scenarios: (a) the target number of trees (n = 200 000) as indicated by the then mayor of the CoJ at the initiation of the project, (b) the number of trees planted as part of the project (n = 206 267) according to the JCPZ tree register, (c) the number of trees verified as existing by a JCPZ audit in 2010 (n = 202 893), (d) the number of trees (n = 199 893) verified as existing by this study and (e) the number of trees with addresses, identified by this study (n = 122 039). The number of trees with addresses refer to the trees that could be found during the field survey. The trees on the tree register listed as “various streets” or with unknown addresses could not be verified. Numbers of trees were extrapolated to estimate existing trees for the GSTP project based on assumptions made from the field survey. This survey revealed a survival rate of 43.46%. Therefore, results are also presented for (f) an estimated 43.46% of the planted trees (n = 206 267) to be alive in 2031 (n = 89 644) and (g) an estimated 43.46% of the number of trees with addresses (n = 122 039) on the JCPZ tree register assumed to be alive in 2031 (n = 53 038). Lastly, results are presented for the (h) estimated existing number of trees (n = 89 644) excluding 15.37% (n = 13 778) missing trees, which is n = 75 886 trees and worst-case scenario, (i) the estimated existing trees with addresses (n = 53 038) excluding 15.37% (n = 8 151) missing trees, which is n = 44 887 trees.

The results for the different scenarios were estimated by dividing the estimated number of trees for the different scenarios by the percentage distribution of the different years of planting (Table 6.20) and by the percentage distribution of the standing trees (Figure 4.5) for each of the measured tree species to form the basis for the sequestered carbon calculations. The carbon for the estimated number of trees was calculated per year of planting, added together and used to extrapolate the total sequestered carbon stock number and the value to 2031.

Results are presented for each species indicating the distribution per species, sequestered carbon for these trees in kg, the total CO_2 measured in tCO_2 and the respective value in South African rand and US dollars for the mean confidence level in 2031 for the different scenarios (Tables 6.22 to 6.30).

6.5.1.1 Estimated sequestered carbon stocks and value for scenario (a)

Results are presented in Table 6.22 for the target number of trees (n = 200 000). The mean confidence level (CL) is a level of 95% of the estimated means (Stoffberg, 2006). If the target number of trees are all still growing in 2031, the standing sequestered carbon of the 200 000 trees is estimated to be 102 290 881.93 kg and the extrapolated CO_2 in 2031 is estimated to be 375 407.54 tCO_2 valued at R45 048 904,40 and US$3,754,075.37.

Table 6.22: Sequestered carbon dioxide quantity and value of target number of trees, projected to 2031

Tree species	Tree distribution	Sequestered carbon (kg)	Sequestered tCO_2	ZAR	US$
Afrocarpus falcatus	3 141	846 136.37	3 105.32	372 638,46	31,053.20
Celtis africana	66 197	28 945 795.16	106 231.07	12 747 728,19	1,062,310.68
Combretum erythrophyllum	59 764	54 043 774.76	198 340.65	23 800 878,41	1,983,406.53
Harpephyllum caffrum	801	189 708.76	696.23	83 547,74	6,962.31
Kiggelaria africana	721	170 737.89	626.61	75 192,97	6,266.08
Olea europaea subsp. *africana*	27 632	6 763 026.82	24 820.31	2 978 437,01	248,203.08
Podocarpus spp.	1 442	325 952.48	1 196.25	143 549,47	11,962.46
Schotia brachypetala	1 571	423 068.18	1 552.66	186 319,23	15,526.60
Senegalia galpinii	3 180	1 229 834.33	4 513.49	541 619,04	45,134.92
Searsia lancea	30 149	7 652 994.57	28 086.49	3 370 378,81	280,864.90
Searsia pendulina	3 598	849 453.52	3 117.49	374 099,33	31,174.94
Vachellia karroo	236	63 460.23	232.90	27 947,88	2,328.99
Vachellia sieberiana var. *woodii*	1 571	786 938.86	2 888.07	346 567,87	28,880.66
Total	**200 000**	**102 290 881.93**	**375 407.54**	**45 048 904,40**	**3,754,075.37**

6.5.1.2 Estimated sequestered carbon stocks and value for scenario (b)

Results are presented in Table 6.23 for the number of trees (n = 206 267) indicated on the tree register as planted as part of the project. If all these trees are still growing in 2031, the sequestered carbon is estimated to be 105 496 166.72 kg and the extrapolated CO_2 in 2031 is estimated to be 387 170.93 tCO_2 with an estimated value of R46 460 511,82 and US$3,871,709.32.

Table 6.23: Sequestered carbon dioxide quantity and value of trees planted, projected to 2031

Tree species	Tree distribution	Sequestered carbon (kg)	Sequestered tCO_2	ZAR	US$
Afrocarpus falcatus	3 240	872 650.05	3 202.63	384 315,08	32,026.26
Celtis africana	68 272	29 852 811.65	109 559.82	13 147 178,25	1,095,598.19
Combretum erythrophyllum	61 636	55 737 236.44	204 555.66	24 546 678,93	2,045,556.58
Harpephyllum caffrum	826	195 653.29	718.05	86 165,71	7,180.48
Kiggelaria africana	743	176 087.96	646.24	77 549,14	6,462.43
Olea europaea subsp. *africana*	28 498	6 974 946.27	25 598.05	3 071 766,34	255,980.53
Podocarpus spp.	1 487	336 166.20	1 233.73	148 047,60	12,337.30
Schotia brachypetala	1 620	436 325.03	1 601.31	192 157,54	16,013.13
Senegalia galpinii	3 279	1 268 371.19	4 654.92	558 590,67	46,549.22
Searsia lancea	31 093	7 892 801.15	28 966.58	3 475 989,63	289,665.80
Searsia pendulina	3 710	876 071.14	3 215.18	385 821,73	32,151.81
Vachellia karroo	243	65 448.75	240.20	28 823,63	2,401.97
Vachellia sieberiana var. *woodii*	1 620	811 597.59	2 978.56	357 427,58	29,785.63
Total	**206 267**	**105 496 166.72**	**387 170.93**	**46 460 511,82**	**3,871,709.32**

6.5.1.3 Estimated sequestered carbon stocks and value for scenario (c)

Results are presented in Table 6.24 for the number of trees verified as existing (n = 202 893) by JCPZ in 2011. If all these trees are still growing in 2031, the standing sequestered carbon of the trees is estimated at 103 770 519.54 kg and the extrapolated CO_2 is estimated to be 380 837.81 tCO_2 with a value of R45 700 536,81 and US$3,808,378.07.

Table 6.24: Sequestered carbon dioxide quantity and value of trees verified as existing by JCPZ in 2010, projected to 2031

Tree species	Tree distribution	Sequestered carbon (kg)	Sequestered tCO_2	ZAR	US$
Afrocarpus falcatus	3 187	858 375.73	3 150.24	378 028,67	31,502.39
Celtis africana	67 155	29 364 496.09	107 767.70	12 932 124,08	1,077,677.01
Combretum erythrophyllum	60 628	54 825 517.96	201 209.65	24 145 158,11	2,012,096.51
Harpephyllum caffrum	812	192 452.90	706.30	84 756,26	7,063.02
Kiggelaria africana	731	173 207.61	635.67	76 280,63	6,356.72
Olea europaea subsp. *africana*	28 031	6 860 854.01	25 179.33	3 021 520,10	251,793.34
Podocarpus spp.	1 463	330 667.38	1 213.55	145 625,92	12,135.49
Schotia brachypetala	1 593	429 187.86	1 575.12	189 014,34	15,751.19
Senegalia galpinii	3 226	1 247 623.88	4 578.78	549 453,56	45,787.80
Searsia lancea	30 585	7 763 695.13	28 492.76	3 419 131,34	284,927.61
Searsia pendulina	3 650	861 740.86	3 162.59	379 510,68	31,625.89
Vachellia karroo	239	64 378.18	236.27	28 352,15	2,362.68
Vachellia sieberiana var. *woodii*	1 593	798 321.93	2 929.84	351 580,98	29,298.41
Total	**202 893**	**103 770 519.54**	**380 837.81**	**45 700 536,81**	**3,808,378.07**

6.5.1.4 Estimated sequestered carbon stocks and value for scenario (d)

Results are presented in Table 6.25 for the number of trees (n = 199 893) verified by this study as the correct number of trees that should have been on the tree register in 2011. If all these trees are still growing in 2031, the standing sequestered carbon of these trees is estimated to be 102 236 156.31 kg and the extrapolated CO_2 is estimated at 375 206.69 tCO_2 with a value of R45 024 803,24 and US$3,752,066.94.

Table 6.25: Sequestered carbon dioxide quantity and value of trees verified, projected to 2031

Tree species	Tree distribution	Sequestered carbon (kg)	Sequestered tCO_2	ZAR	US$
Afrocarpus falcatus	3 140	845 683.68	3 103.66	372 439,09	31,036.59
Celtis africana	66 162	29 478 669.88	108 186.72	12 982 406,22	1,081,867.18
Combretum erythrophyllum	59 732	50 865 289.11	186 675.61	22 401 073,32	1,866,756.11
Harpephyllum caffrum	800	189 607.27	695.86	83 503,04	6,958.59
Kiggelaria africana	720	170 646.54	626.27	75 152,74	6,262.73
Olea europaea subsp. *africana*	27 617	6 759 408.60	24 807.03	2 976 843,55	248,070.30
Podocarpus spp.	1 441	325 778.10	1 195.61	143 472,67	11,956.06
Schotia brachypetala	1 570	422 841.84	1 551.83	186 219,55	15,518.30
Senegalia galpinii	3 178	1 229 176.37	4 511.08	541 329,27	45,110.77
Searsia lancea	30 132	7 648 900.22	28 071.46	3 368 575,66	280,714.64
Searsia pendulina	3 596	848 999.06	31 15.83	373 899,19	31,158.27
Vachellia karroo	235	63 426.28	232.77	27 932,93	2,327.74
Vachellia sieberiana var. *woodii*	1 570	786 517.85	2 886.52	346 382,46	28,865.21
Total	**199 893**	**102 236 156.31**	**375 206.69**	**45 024 803,24**	**3,752,066.94**

6.5.1.5 Estimated sequestered carbon stocks and value for scenario (e)

Results are presented in Table 6.26 for the number of trees (n = 122 039) identified by this study as trees with addresses on the tree register. If all these trees are still growing in 2031, the sequestered carbon of the trees is estimated to be 7 350 024 457.02 kg and the extrapolated CO_2 is estimated to be 269 754.02 tCO_2 at a value of R24 110 470,45 and US$2,697,540.18.

Table 6.26: Sequestered carbon dioxide quantity and value of trees with addresses on JCPZ tree register, projected to 2031

Tree species	Tree distribution	Sequestered carbon (kg)	Sequestered tCO_2	ZAR	US$
Afrocarpus falcatus	1 917	845 683.68	3 103.66	372 439,09	31,036.59
Celtis africana	3 788 374	23 587 507.65	86 566.15	8 643 389,51	886,659.43
Combretum erythrophyllum	2 485 930	35 406 398.83	129 941.48	9 819 169,71	1,13,133.60
Harpephyllum caffrum	489	115 759.34	424.84	50 980,41	4,248.37
Kiggelaria africana	440	104 183.41	382.35	45 882,37	3,823.53
Olea europaea subsp. africana	867 655	4 958 998.16	18 199.52	1 845 345,08	186,764.12
Podocarpus spp.	880	198 894.57	729.94	87 593,17	7,299.43
Schotia brachypetala	958	422 841.84	1 551.83	186 219,55	15,518.30
Senegalia galpinii	3 138 006	750 438.76	2 754.11	541 329,27	45,110.77
Searsia lancea	938 907	5 718 771.42	20 987.89	1 983 818,95	215,038.40
Searsia pendulina	2 195	543 035.45	1 992.94	159 987,94	19,929.40
Vachellia karroo	144	63 426.28	232.77	27 932,93	2,327.74
Vachellia sieberiana var. woodii	958	786 517.85	2 886.52	346 382,46	28,865.21
Total	**122 039**	**73 502 457.23**	**269 754.02**	**24 110 470,45**	**2,697,540.18**

6.5.1.6 Estimated sequestered carbon stocks and value for scenario (f)

Results are presented in Table 6.27 for the estimated existing trees (n = 89 644) of this project in 2031. This number is based on a 43.46% survival rate of the planted trees (n = 206 267). The sequestered carbon of the 89 644 trees is estimated to be 45 848 819.10 kg and the extrapolated CO_2 is estimated to be 168 265.17 tCO_2 valued at R20 191 819,93 and US$1,682,651.66.

Table 6.27: Sequestered carbon dioxide quantity and value of estimated existing trees, projected to 2031

Tree species	Tree distribution	Sequestered carbon (kg)	Sequestered tCO_2	ZAR	US$
Afrocarpus falcatus	1 408	379 255.24	1 391.87	167 024,01	13,918.67
Celtis africana	29 671	12 974 084.31	47 614.89	5 713 786,73	476,148.89
Combretum erythrophyllum	26 787	2 423 500.72	88 900.25	10 668 029,72	889,002.48
Harpephyllum caffrum	359	85 031.26	312.06	37 447,77	3,120.65
Kiggelaria africana	323	76 528.14	280.86	33 70299	2,808.58
Olea europaea subsp. *africana*	12 385	3 031 323.88	11 124.96	1 334 995,04	111,249.59
Podocarpus spp.	646	146 098.42	536.18	64 341,74	5,361.81
Schotia brachypetala	704	189 627.62	695.93	83 512,00	6,959.33
Senegalia galpinii	1 425	551 236.34	2 023.04	242 764,48	20,230.37
Searsia lancea	13 513	3 430 225.23	12 588.93	1 510 671,19	125,889.27
Searsia pendulina	1 613	380 742.06	1 397.32	167 678,80	13,973.23
Vachellia karroo	106	28 444.14	104.39	12 526,80	1,043.90
Vachellia sieberiana var. *woodii*	704	352 721.74	1 294.49	155 338,65	12,944.89
Total	**89 644**	**45 848 819.10**	**168 26517**	**20 191 819,93**	**1 682,651.66**

6.5.1.7 Estimated sequestered carbon stocks and value for scenario (g)

Results are presented in Table 6.28 for an estimated 43.46% (n = 53 038) of the trees with addresses on the JCPZ tree register (n = 122 039), assumed to be alive in 2031. The sequestered carbon of these trees is estimated to be 27 126 518.98 kg and the extrapolated CO_2 in 2031 is estimated to be 99 554.32 tCO_2 at a value of R11 946 518,96 and US$995,543.25.

Table 6.28: Sequestered carbon dioxide quantity and value of estimated existing trees with addresses, projected to 2031

Tree species	Tree distribution	Sequestered carbon (kg)	Sequestered tCO_2	ZAR	US$
Afrocarpus falcatus	833	224 386.90	823.50	98 819,99	8,235.00
Celtis africana	17 555	7 676 135.42	28 171.42	3 380 570,04	281,714.17
Combretum erythrophyllum	15 849	14 331 868.63	52 597.96	6 311 754,94	525,979.58
Harpephyllum caffrum	212	50 308.87	184.63	22 156,03	1,846.34
Kiggelaria africana	191	45 277.98	166.17	19 940,42	1,661.70
Olea europaea subsp. *africana*	7 328	1 793 487.08	6 582.10	789 851,71	65,820.98
Podocarpus spp.	382	86 439.34	317.23	38 067,88	3,172.32
Schotia brachypetala	417	112 193.45	411.75	49 410,00	4,117.50
Senegalia galpinii	843	326 139.77	1 196.93	143 631,95	11,969.33
Searsia lancea	7 995	2 029 497.63	7 448.26	893 790,76	74,482.56
Searsia pendulina	954	225 266.58	826.73	99 207,40	8,267.28
Vachellia karroo	62	16 829.02	61.76	7 411,50	617.62
Vachellia sieberiana var. *woodii*	417	208 688.32	765.89	91 906,33	7,658.86
Total	**53 038**	**27 126 518.98**	**99 554.32**	**11 946 518,96**	**995,543.25**

6.5.1.8 Estimated sequestered carbon stocks and value for scenario (h)

Results are presented in Table 6.29 for the estimated existing trees (n = 89 644) of this project in 2031, excluding 15.37% (n = 13 778) missing trees (n = 75 886) on the JCPZ tree register. The sequestered carbon of these trees is estimated to be 38 802 000.24 kg and the extrapolated CO_2 in 2031 is estimated to be 142 403.34 tCO_2 at a value of R17 088 400,91 and US$1,424,033.41.

Table 6.29: Sequestered carbon dioxide quantity and value of 15.37% of the estimated existing trees, projected to 2031

Tree species	Tree distribution	Sequestered carbon (kg)	Sequestered tCO_2	ZAR	US$
Afrocarpus falcatus	1 192	320 964.91	1 177.94	14 1352,95	11,779.41
Celtis africana	25 111	10 980 008.48	40 296.63	4 835 595,73	402,966.31
Combretum erythrophyllum	22 670	20 500 425.08	75 236.56	9 028 387,21	752,365.60
Harpephyllum caffrum	304	71 962.23	264.10	31 692,16	2,641.01
Kiggelaria africana	273	64 766.00	237.69	28 522,95	2,376.91
Olea europaea subsp. *africana*	10 482	2 565 418.97	9 415.09	1 129 810,51	94,150.88
Podocarpus spp.	547	123 643.55	453.77	54 452,62	4,537.72
Schotia brachypetala	596	160 482.45	588.97	70 676,47	5,889.71
Senegalia galpinii	1 206	466 513.06	1 712.10	205 452,35	17,121.03
Searsia lancea	11 436	2 903 010.43	10 654.05	1 278 485,79	106,540.48
Searsia pendulina	1 365	322 223.20	1 182.56	141 907,10	11,825.59
Vachellia karroo	89	24 072.37	88.35	10 601,47	883.46
Vachellia sieberiana var. *woodii*	596	298 509.52	1 095.53	131 463,59	10,955.30
Total	75 866	38 802 000.24	142 403.34	17 088 400,91	1,424,033.41

6.5.1.9 Estimated sequestered carbon stocks and value for scenario (i)

Finally, the worst-case scenario results are presented in Table 6.30 for 44 887 trees, being the estimated existing trees with addresses (n = 53 038) of this project, less 15.37% missing trees (n = 8 151) in 2031. The sequestered carbon of the trees (n = 44 887) is estimated to be 22 957 654.09 kg and the extrapolated CO_2 in 2031 is estimated to be 84 254.59 tCO_2 with a value of R10 110 550,86 and US$842,545.90.

Table 6.30: Sequestered carbon dioxide quantity and value of trees estimated as the number of trees with addresses on JCPZ tree register less missing trees, projected to 2031

Tree species	Tree distribution	Sequestered carbon (kg)	Sequestered tCO_2	ZAR	US$
Afrocarpus falcatus	705	189 902.62	696.94	83 633,11	6,969.43
Celtis africana	14 857	6 496 449.54	23 84197	2 861 036,38	238,419.70
Combretum erythrophyllum	13 413	12 129 314.59	44 514,.58	5 341 750,14	445,145.85
Harpephyllum caffrum	180	42 577.29	156.26	18 751,04	1,562.59
Kiggelaria africana	162	38 319.56	140.63	16 875,93	1,406.33
Olea europaea subsp. *africana*	6 202	1 517 859.93	5 570.55	668 465,51	55,705.46
Podocarpus spp.	324	73 155.15	268.48	32 217,53	2,684.79
Schotia brachypetala	353	94 951.31	348.47	41 816,56	3,484.71
Senegalia galpinii	714	276 017.87	1 012.99	121 558,27	10,129.86
Searsia lancea	6 766	1 717 599.84	6 303.59	756 430,97	63,035.91
Searsia pendulina	807	190 647.10	699.67	83 960,98	6,996.75
Vachellia karroo	53	14 242.70	52.27	6 272,48	522.71
Vachellia sieberiana var. *woodii*	353	176 616.62	648.18	77 781,96	6,481.83
Total	**44 887**	**22 957 654.09**	**84 254.59**	**10 110 550,86**	**842,545.90**

6.5.2 Summary of estimated projected sequestered carbon quantity and value for the different scenarios

A summary of the carbon dioxide quantity and value for the different scenarios is provided in Table 6.31. The summary shows how the carbon value differs per estimated scenario. These numbers are estimates at best but because they are based on the same biomass and growth equations for all the species, they can be used to compare the carbon stock quantity and the value of the different scenarios with each other.

Table 6.31: Summary of projected carbon sequestered and value for different scenarios, 2001 - 2031

Scenario	Tree distribution	Sequestered carbon (kg)	Sequestered tCO_2	ZAR	US$
b	206 267	105 496 166.72	387 170.93	46 460 511,82	3,871,709.32
c	202 893	103 770 519.54	380 837.81	45 700 536,81	3, 808,378.07
a	200 000	102 290 881.93	375 407.54	45 048 904,40	3,754,075.37
d	199 893	102 236 156.31	375 206.69	45 024 803,24	3,752,066.94
e	122 039	73 502 457.23	269 754.02	24 110 470,45	2,697,540.18
f	89 644	45 848 819.10	168 265.17	20 191 819,93	1,682,651.66
h	75 866	38 802 000.24	142 403.34	17 088 401,91	1,424,033.41
g	53 038	27 126 518.98	99 554.32	11 946 518,96	995,543.25
i	44 887	22 957 654,09	84 254,59	10 110 550,86	842,545.90

It is estimated that if the aim of the GSTP project were realised and the target number (n = 200 000) of trees were still alive in 2031, the estimated value of the project could have been R45 048 904,40 or US$3,754,075.37. However, more trees were planted and if all these trees (n = 206 267) are still alive in 2031, the value would be R46 460 511,82 or US$3,871,709.32. The difference between the estimated value of the planted trees and the target number of trees would be R1 411 607,42 or US$117,633.95 if all the trees that were planted are still alive in 2031.

As the tree numbers in the scenarios displayed in Table 6.31 reduce, the estimated carbon sequestered and the value reduce proportionately. The difference in the estimated projected values of the target number of trees (n = 200 000) of the GSTP project (R45 048 904,40 or US$3,754,075.37) and the estimated number of existing trees (n = 89 644) of this project, which is 43.46% of the number of planted trees (n = 206 267), amounts to R20 191 819,93 or US$1,682,651.66, expressing a loss of 56.54% in the value of the project. Assuming that the 15.37% missing trees found in the survey is repeated across the study, the worst-case scenario is estimated to be 44 887 trees. This is determined by using the trees with addresses of this project (n = 53 038) as a basis and removing the 15.37% (n = 8 151) missing trees. The missing trees are the trees identified as dead or just stumps and stumps with coppice growth, coppice growth only and absent trees during the physical survey. The value of this scenario (R10 110 550,86 or US$842,545.90) is 22.44% of the value of the target number of trees (n = 200 000) of the GSTP project, corresponding to a loss of 77.56% in the value of the project.

6.6 Discussion

The carbon assessment and value determination of the standing carbon stock for the GSTP project indicate that the high numbers of three tree species in the study, i.e. *C. africana, C. erythrophyllum* and *S. lancea,* contributed 85.6% to the total standing carbon in the study. When comparing standing carbon in the regions with each other, the regions with the most trees in the study contributed more to the total standing carbon than those with fewer trees. However, the percentage distribution of the trees in the different regions did not correlate with the percentage distribution of the total standing CO_2 per region. It was revealed that where regions contributed less to the standing CO_2 than the number of trees indicated they should, the trees in those regions had smaller circumferences than in the other regions and vice versa. These results confirm that the wider the circumference of the tree, the higher the carbon value of the tree. The tree species with the highest mean standing carbon stock per tree was *V. sieberiana* var. *woodii* which were the largest trees measured (mean circumference of 667 mm). The *Podocarpus* spp. had the lowest mean total carbon stock per tree species with the smallest mean circumference (236 mm).

Most of the standing carbon stock was stored by the trees planted during the first year (2005) of the GSTP project. The least standing carbon stock was accumulated and stored by the trees planted during the last year (2010) of the project, confirming that the longer trees grow, the larger they become, resulting in increases in biomass and carbon storage (McPherson, 1994).

Due to the high number (81.2%; n = 1 379) of trees planted on sidewalks, trees in this location accumulated and stored most (55%) of the total standing carbon in this study; 18.7% of the trees (n = 319) were planted on the medians and they stored the least (12.77%). Kiran & Kinnary (2011) reports that trees planted on roadsides of Vadodara city contributed 73.59 tCO_2, representing 22% of the city's estimated total CO_2 production. The street trees in this current study contributed 67.77% to the total carbon. The median and sidewalk trees had the same mean standing carbon per tree (0.16 tCO_2), which was larger than the mean of the trees in parks (0.12 tCO_2), indicating that street trees have a wider mean circumference and are assumed to be larger than the park trees. This correlates with the planting dates of the trees. The street trees were mostly planted before the park trees and were therefore older. However, these results are contradictory to the results presented in Chapter 5 of this study, where it was found that park trees grow better than street trees as the growth parameters of the trees planted in parks were larger than those of the trees planted in streets. Therefore, it cannot be stated that the tree with the widest stem circumference is the tallest or largest tree in this study. This difference was attributed to applying different growth parameters in the different parts of the study. For the results in Chapter 5, VolCalc was used for tree height (m), height of maximum canopy diameter (m), height at first leaf (m), maximum canopy diameter (m), stem diameter at first leaf (m) and volume (m^3). The calculations adopted in this chapter (Chapter 6) required the use of tree circumference and was the only growth parameter reported on.

If all the trees that were planted (n = 206 267) were alive in 2017, the total standing carbon stock of the trees would have been 8 280 683.17 kg and 30 390.11 tCO_2, valued at R3 646 812,87 or US$303,901.07. The mean standing carbon stock was 40.14 kg/tree or 0.040 t/tree and 0.15 tCO_2 per tree. The carbon stock was much less than the mean standing carbon stock of the trees in the study by Chavan and Rasal (2010), who found the mean carbon stock to be approximately 1.65 t/tree. Their study did not provide information on tree ages and circumference measurements but included large species such as *Ficus bengalensis, Ficus religiosa* and *Mangifera indica,* described as "well grown"; this could be responsible for the higher quantity of carbon stock per tree. No international study on standing carbon stocks of young trees could be found.

It was estimated that only 43.46% of the planted trees were alive in 2017, showing a loss in carbon stocks of 56.54%. Estimating a worst-case scenario by removing the missing trees (15.37%) from the trees without addresses resulted in loss of 77.44% in the value of the project. As trees make up more than 95% of the urban vegetation carbon sink (Davies et al., 2011), the loss is concerning and implies a lack of structured aftercare and maintenance, highlighting the need for a tree planting and maintenance specification.

International studies used US$ for the entire project and an annual sequestration value of US$ per year for the urban forest of the city (Nowak & Crane, 2002; Nowak et al., 2013). The value of the carbon stocks in this current study is reported on in ZAR as well as US$ to enable possible comparisons. Studies reporting on standing carbon stocks in urban environments were conducted in India. These studies reported on standing carbon stocks on University Campus at Aurangabad, Maharashtra, India (Chavan & Rasal, 2010) and 36 parks in Delhi to demonstrate the role of trees in carbon mitigation (Tripathi & Joshi, 2015). However, these studies referred to standing carbon stocks only and did not calculate the total standing carbon stocks for the project or their relevant monetary value.

An estimation of the potential projected carbon sequestration over a period of 30 years by 2031, for different scenarios of the project, was made and the monetary value of the projected carbon sequestered by these trees was calculated. Calculating the monetary value using a carbon price of US$10 per tCO_2 has typically been used to quantify the benefits of carbon storage and sequestration by urban forests (McPherson, 1998; Nowak & Crane, 2002). It is estimated that in 2031, the GSTP project could have sequestered a potential quantity of 375

407.54 tCO_2 valued at R45 048 904,40 or US$3,754,075.37 if the target number (n = 200 000) of the trees were still alive.

Schäffler and Swilling (2013) conducted a green infrastructure valuation study in the city of Johannesburg following a carbon assessment methodology using a 50 × 50 m^2 plot representing an urban tree stand. They estimated this area stored 32.2 metric tons of carbon per hectare (ha). Extrapolated to city level (164 458 ha), the total sequestered carbon stock was 5.3 million metric tons and, employing a market-related carbon price of US$12.10 per ton, the carbon stock was valued at US$64,154,910.00 in 2010.

Adopting the 39 trees per ha methodology employed in the Schäffler and Swilling study, an extrapolation was made of the carbon stock of the GSTP project to city level. After applying the results of the estimated projected carbon sequestered by 2031 determined in this study, mean quantities of sequestered carbon per tree were determined. The mean quantities were 102 209 881 kg (511.15 kg/tree) and 375 407.54 tCO_2 (1.87 tCO_2 /tree). Multiplying these quantities by 39 trees produces 719 934.85 kg/ha sequestered carbon and 72.93 tCO_2/ha. It is estimated that the projected total sequestered carbon stock for the CoJ (164 458 ha) in 2031 could be 119 838 915 261 kg carbon and 11 993.921 tCO_2 valued at R1 439 270,63 or US$119,939.21 using a carbon price of R120 and US$10 per tCO_2. The value estimation of this study is based on young indigenous trees, whereas the Schäffler and Swilling study was conducted with unidentified mature trees at an average height of 10 m.

Carbon sequestration assessments are conducted for entire cities such as Florence, Italy (Vaccari, Gioli, Toscano & Perrone, 2013), Shenyang in China (Liu & Li, 2012), for a number of cities in the USA (Nowak & Crane, 2002), for regions such as the Hangzhou region in China (Zhao, Kong, Escobedo & Gao, 2010) and the Chicago region in the USA (Nowak, Hoehn, Bodine, Crane, Dwyer, Bonnewell & Watson, 2013). As for this study, the carbon sequestration assessment was conducted for a tree planting project and is similar in principle to the million tree projects in Los Angeles (McPherson et al., 2008) and New York City (Morani et al., 2011). However, the US projects are reported on continuously. This is the first study conducted for a specific tree planting project consisting of indigenous trees in the CoJ in South Africa.

It is problematic to compare the carbon storage results of this study with international carbon storage results. Generally, studies report on annual sequestration rates in tons per unit of tree cover or area (per ha, per year) (Nowak & Crane, 2002; Aguaron & McPherson, 2012; Nowak et al., 2013), as total carbon storage and sequestration within a city (Nowak & Crane, 2002) and per canopy cover or land cover type (Strohbach & Haase, 2012). The tons per hectare methodology seems to be a valuable reporting tool as it can be used to relate the carbon results of one city, region or suburb with those of another. Prabha, Muniyandi, Kumar, Nagendran and Prabha (2020) used this methodology and report that the national average urban forest carbon storage density in the USA is 25.1 tC/ha compared to 53.5 tC/ha in natural forests. Comparing these quantities with those from this current study, the quantity carbon sequestered per ha for this study was 14.26 tC/ha, which is much less than the national average in the USA. However, it must be noted that the estimation for the trees in the CoJ is only for a period of 30 years of growth and on 13 species. Aguaron and McPherson (2012) caution that the difference in forest composition, age structure and planting density make it difficult to compare CO_2 storage and sequestration.

In the carbon sequestration of indigenous trees in the city of Tshwane by Stoffberg et al. (2010), it was determined that the 115 200 street trees would sequester a potential quantity of 200 492 tCO_2 valued at US$3,006,435.00 by 2031. If compared to this current study using the number of trees that were verified by the physical survey (n = 122 039), the carbon stocks would be 269 754.02 tCO_2 by 2031 valued at R24 110 470,45 or US$2,759,754.89. Stoffberg et al. (2010) used a market-related price of US$15.00/$tCO_2$ compared to the US$10.00/$tCO_2$ of this study. Reporting the same sequestered carbon stocks using US$10.00/$tCO_2$ as the value determinant, the value of the carbon stock in the Tshwane study would be US$2,004,920.00 by 2031 (Stoffberg, 2006). The mean value of the trees in the city of Tshwane would then be US$17.40 per tree in 2031, compared to the mean value of US$18.77 per tree in 2031 for the trees in this current study. The trees in the city of Tshwane were younger than the trees in the CoJ to start with, but it was found that the circumference growth of the trees in both cities grows and matures at a similar rate. Generally, large healthy trees store and sequester more carbon than small healthy trees (Nowak, 1994).

6.7 Conclusion

The objective was to complete a carbon assessment and determine the value of the GSTP project. This objective included the determination of standing carbon stocks for the project, an estimation of the potential projected carbon sequestration over a period of 30 years for different scenarios of the project and a determination of the monetary value of the standing and projected carbon sequestered by these trees.

Although the aim of the GSTP project was to transform the dry, dusty streets and landfills in the previously disadvantaged areas in the CoJ, this project has the potential to contribute to national and international climate change mitigation initiatives (Nowak & Crane, 2002). The Kyoto Protocol recognises carbon sequestration and storage as a valid means to mitigate climate change (Grace & Basso, 2012) and identifies carbon sequestration as one of the CDM strategies (United Nations, 1998). The carbon sequestered by trees can be determined and quantified as mitigation action against climate change (McHale et al., 2007). Therefore, the GSTP project contributed 30 390.11 tCO_2 of standing carbon stocks valued at R3 646 812,87 or US$303,901.07 in 2017 and could potentially contribute 387 170.93 tCO_2 of sequestered carbon stocks valued at R46 460 511,82 or US$3,871,709.32 in 2031 as mitigation action against climate change.

Carbon trading projects could present an opportunity to local governments to become active and in the offset markets as revenue can be generated while preserving urban forests and providing a wide range of other benefits to society (Poudyal et al., 2012). This study provides valuable information for future carbon trading opportunities and shows that carbon sequestration value increases as the number of trees increases. If all the planted trees (n = 206 267) are still alive in 2031, the value could be R46 460 511,82 or US$3,871,709.32, which is more than the worst-case scenario of the estimated existing trees with addresses less 15.37% missing trees (n = 44 887) valued at R10 110 550,86 or US$842,545.90. This indicates a loss of 77.56% in the carbon value of the project as a worst-case scenario, confirming the importance of the correct choice of tree species along with implementing best practice planting and maintenance specifications to ensure that the planted trees survive and grow to a mature state, and thus store the most carbon possible, thereby contributing effectively to climate change mitigation.

These results raised questions as to reasons for the differences in the standing and sequestered carbon quantities and value as well as the variation in sizes of trees planted on sidewalks and medians in streets, in parks and in different regions in the city. The findings of this study justify the need for guidance in the form of a tree planting framework to prevent high mortality rates in future tree planting projects and to realise the sequestered carbon value of the trees and climate change mitigation.

CHAPTER 7

THE IMPACT OF LAND USE, LAND COVER AND EXTERNAL FACTORS ON TREE GROWTH

7.1 Introduction

The findings of the inventory analysis, the growth parameter interaction of the trees and the carbon assessment highlight the variation in the growth and size of the trees assessed in this project. The aim of this chapter is to identify factors that could contribute to this variation. The impact of land use, land cover and external factors such as the type of tree maintenance required, the impact of human influence, conflict or damage caused by infrastructure and the presence of pests and diseases on the growth of the trees was investigated. The results are presented as categorical data and are reported mainly as percentages. Categorical data defines the categories of data in the study. Lu et al. (2010) used categorical data to determine factors affecting young tree mortality. Results are presented and interpreted for the distribution of each of the land uses, land covers and external factors for all the tree species (n = 2 498) and the missing trees (n = 410) in the study. The impact of land use, land cover and the external factors on four of the tree species in the study is illustrated. Finally, the VolCalc growth relationship results for the species with the most trees in the study are presented and discussed in relation to the land use, land cover and external factor results. Hypothesis testing (Spearman's rank correlation) was conducted to determine the relationship between variables and the significance of the results. Reasons are provided for the differences in the results.

The land use, land cover and external factor categories – tree maintenance required, impact of human influence, conflict or damage caused by infrastructure and presence of pests and diseases – are defined in the methods chapter. Single categories are defined but where more than one category was identified in close proximity to (for the land use and conflict categories) or within 1 000 mm surrounding the tree stem (for land cover and human influence categories) or on the tree (for maintenance required and pests and diseases categories), these categories were combined.

7.2 Distribution of land use, land cover and external factors

The results are presented in alphabetical order in the figures and the tables. The external factor categories are maintenance needs, the presence of pests and diseases, the impact of human influence and conflict or damage caused by infrastructure.

7.2.1 Distribution of land use for all the tree species

Eleven land use categories were identified and are described in the methodology chapter of this thesis. Figure 7.1 shows that 51% of the trees in the study were planted in either the “parks” land use (31%; n = 771) or in the “formal residential” land use (20%; n = 499) on sidewalks. Combined, the other land uses comprise 49% (n = 1 242) of the trees.

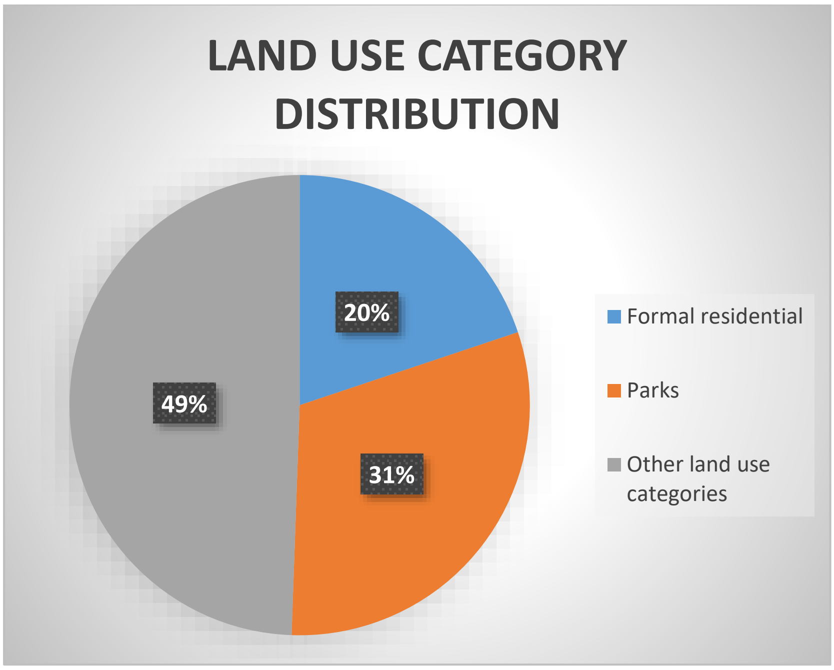


Figure 7.1: Distribution of land use for the major land uses in the study comprising of 51% of the trees

Figure 7.2 illustrates the distribution of the other 49% of the trees, consisting of the “commercial” land use (15%;, n = 183), “formal residential and median” land use (14%; n = 178), “vacant land” land use (12%; n = 154) and “education” land use (12%; n = 148). The remainder of the trees (47%; n = 579) were distributed over 16 land use categories, each with 7% and less of the trees. 7% of the trees (n = 84) were found in “commercial and meridian” land uses, 5% in “sport complexes” (n = 62) and 4% each in “religious” complexes and “industrial” areas (n = 48) and “formal residential and vacant land” areas (n = 46). 3% each of the trees were found in the “medians and informal residential” land use areas (n = 43), “formal residential and education” land uses (n = 43), “formal residential and commercial” land uses (n = 42) and “medians next to vacant land” (n = 39). The remainder of the trees (8%) were spread over the other six land uses. By combining the land uses where there was more than one land use near the tree, too many land uses were created, which spread the distribution in small percentages.

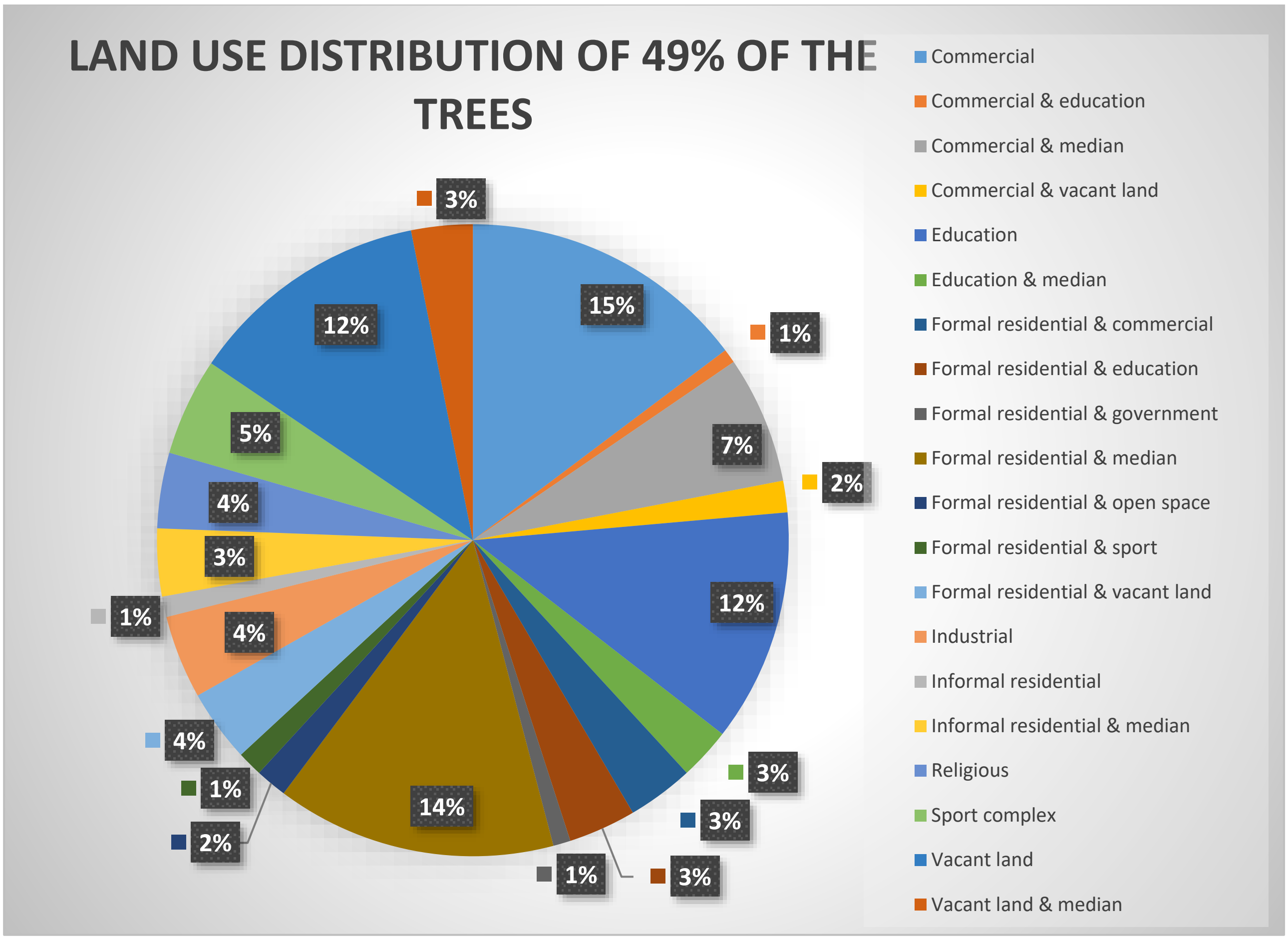


Figure 7.2: Distribution of land use for remaining 49% of tree species across the minor land uses

The percentage distribution of the land use categories for the tree species in the study is presented in Table 7.1. Results of the four species with the most trees in the study are analysed and discussed. The species with fewer than 50 trees in the sample did not provide noteworthy results as they were found in only one or two of the land use categories.

The results of *C. africana* (n = 885) (Table 7.1) indicate that 23.6% of the trees were planted in the "parks", 17% in the "formal residential" and 10% in the "vacant land" land use categories. The remainder of the *C. africana* trees were distributed across 17 different land use categories with less than 10% per land use category. A noticeable number of trees (18.5%) were planted in the land use categories linked to the median and a small number of trees (2.4%; n = 48) were planted in the "industrial" land use category.

The results of *C. erythrophyllum* (n = 874) (Table 7.1) show that the trees were planted mostly in the land use category "parks" (48.5%), followed by "formal residential" (20.1%) and "formal residential and median" (8.9%). The rest of the *C. erythrophyllum* trees (22.5%) were distributed across nine different land use categories with less than 10% per land use category.

The results of *O. europaea* subsp. *africana* (n = 414) (Table 7.1) reveal that the trees were planted in the land use category “parks” (47.4%), then “formal residential” (23.5%), “formal residential and median” (10.2%) and “commercial” (8.4%). The rest of the *O. europaea subsp. africana* trees (10.5%) were distributed across six different land use categories in percentages of less than 5% per land use category.

The results of *S. lancea* (n = 465) (Table 7.1) show that the trees were planted in the land use category “parks” (37.4%), “formal residential” (21.3%), “formal residential and median” (10.5%) and “commercial” (8.7%). The rest of the *S. lancea* trees (32.1%) were distributed across six different land use categories with less than 5% per land use category.

Table 7.1: Percentages of land use categories for each tree species

Land use categories	*Afrocarpus falcatus*	*Celtis africana*	*Combretum erythrophyllum*	*Harpephyllum caffrum*	*Kiggelaria africana*	*Olea europaea* subsp. *africana*	*Podocarpus* spp.	*Schotia brachypetala*	*Searsia lancea*	*Searsia pendulina*	*Senegalia galpinii*	*Vachellia karroo*	*Vachellia sieberiana* var. *woodii*
Commercial	_	4.5	5.9	100		8.4	_	_	8.7	_	51.2	_	_
Commercial and education	_	1.1	_	_	_	_	_	_	_	_	48.8	_	_
Commercial and median	_	4.2	_	_	_	_	_	_	5.3	_	_	_	_
Commercial and vacant land	_	2.4	_	_	_	_	_	_	_	_	_	_	100
Education	_	5.7	_	_	_	_	_	_	_	_	_	_	_
Education and median	_	3.9	_	_	_	_	_	_	_	_	_	_	_
Formal residential	_	17.0	20.1	_	_	23.5	_	_	21.3	69	_	_	_
Formal residential and commercial	_	2.4	_	_	_	0.6	_	_	_	_	_	_	_
Formal residential and education	_	1.7	1.8	_	_	5.0	_	_	_	_	_	_	_
Formal residential and government	_	_	1.0	_	_	_	_	_	_	_	_	_	_
Formal residential and industrial	_	2.3	0.3	_	_	_	_	_	_	_	_	33.3	_
Formal residential and median	50	1.2	8.9	_	100	10.2	_	_	10.5	_	_	_	_
Formal residential and sport	_	_	2.2	_	_	_	_	_	5.3	_	_	_	_
Formal residential and vacant land	_	2.1	3.0	_	_	1.9	_	_	_	_	_	_	_
Government	_	5.6	_	_	_	0.3	_	_	3.7	_	_	_	_
Industrial	_	2.4	2.9	_	_	_	_	_	1.8	_	_	_	_
Industrial and open space	_	0.2	_	_	_	_	_	_	_	_	_	_	_
Informal residential	_	1.2	_	_	_	_	_	_	_	_	_	_	_
Informal residential and median	_	4.6	_	_	_	_	_	_	_	_	_	_	_
Park	50	23.6	48.5	_	_	47.4	100	100	37.4	27.4	_	_	_
Religious	_	_	0.3	_	_	_	_	_	_	_	_	_	_
Vacant land	_	10.0	5.2	_	_	2.8	_	_	4.2	3.4	_	_	_
Vacant land and median	_	3.8	_	_	_	_	_	_	1.8	_	_	66.6	_
Total percentage	100	100	100	100	100	100	100	100	100	100	100	100	100

7.2.2 Distribution of land cover for all the tree species

The distribution of the land cover categories where the trees in the study were planted is presented in Figure 7.3. Most of the trees in the study (52%; n = 1319) were planted in "maintained lawn" areas, 13% (n = 339) in the land cover "bare soil" and 13% (n = 338) in areas referred to as "unmaintained grass". The remaining 22% (n = 551) trees were distributed over 12 land cover categories (Figure 7.4).

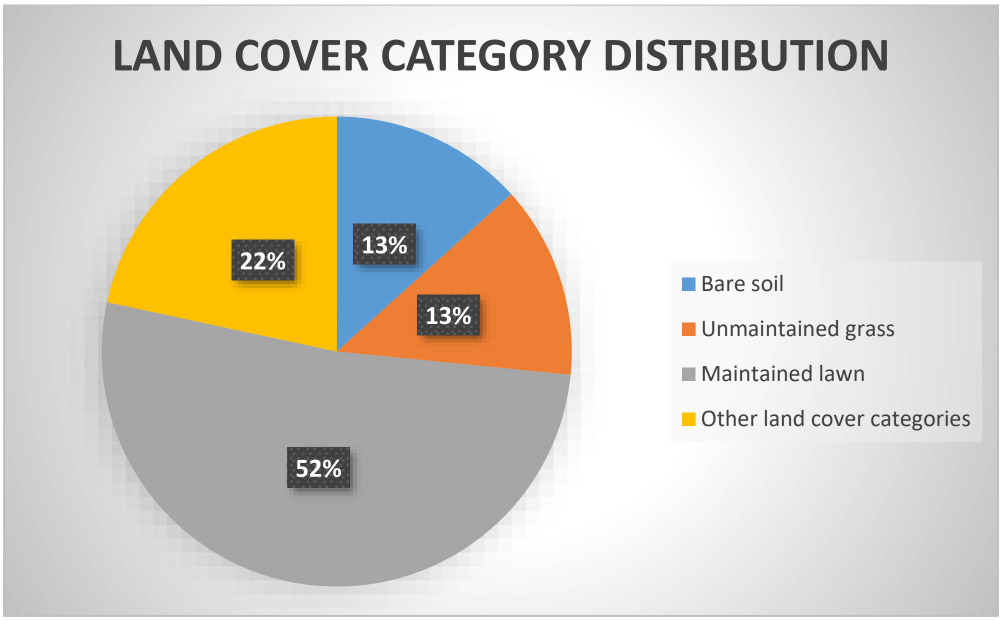


Figure 7.3: Distribution of land cover for all the tree species in the study

Of the remaining 22% of the trees (indicated in yeallow on the graph in Figure 7.3), 27% (n = 150) were found in the land cover "paving", 14% (n = 75) in "plant bed" and 11% (n = 58) in "maintained lawn and bare soil". The other 48% (n = 268) were found in nine land cover categories, each representing less than 10% of the trees.

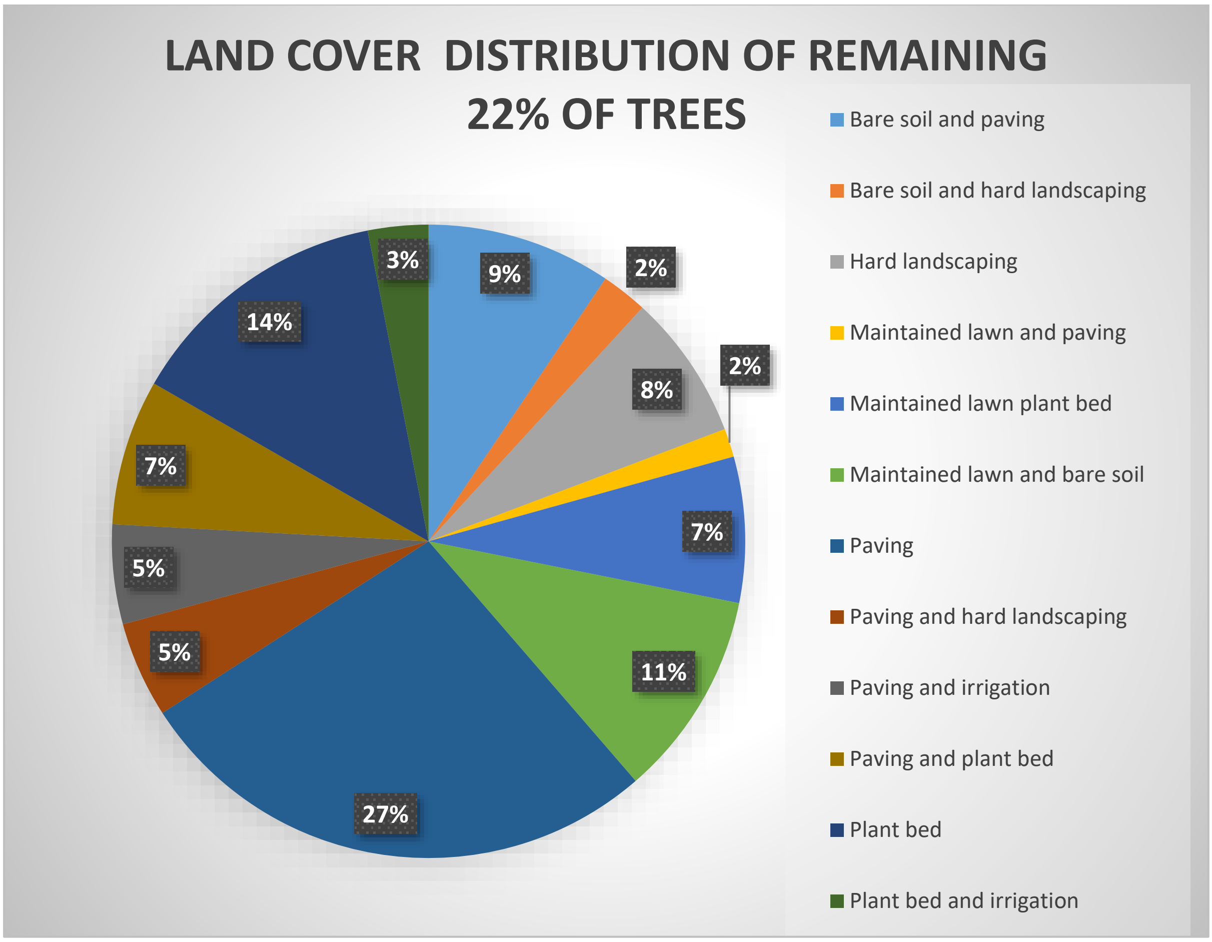


Figure 7.4: Distribution of land cover categories for remaining 22% of the trees not allocated to bare soil, unmaintained grass and maintained lawn

The results of the percentage distribution of the land cover categories for all the tree species in the study are presented in Table 7.2. The four tree species with the most trees in the study are analysed and discussed. The tree species with fewer than 50 trees in the sample did not provide noteworthy results as they were only found in one or two of the land cover categories.

The results of *C. africana* (Table 7.2) indicate that 60.6% of the trees were found in the land cover category "maintained grass", 13.9% in "bare soil" and 10.7% in "unmaintained grass". The rest of the trees (14.8%) were planted in eight land cover categories at less than 5% per land cover category.

The results of *C. erythrophyllum* (Table 7.2) show that 54.5% of the trees were growing in the land cover category "maintained grass", 16.2% in "bare soil" and 14.3% in "unmaintained grass". The rest of the trees (15%) were planted across 11 land cover categories at less than 4% per land cover category.

The results of *O. europaea* subsp. *africana* (Table 7.2) reveal that 49.8% of the trees were found in the land cover category "maintained grass", 28.2% in "bare soil", 11.5% in "paving" and 6.2% in “maintained grass and bare soil”. The rest of the trees (4.3%) were planted across four land cover categories at less than 3% per land cover category.

The results of *S. lancea* (Table 7.2) show that 43.3% of the trees were growing in the land cover category “maintained grass”, 18.2% in “unmaintained grass”, 9.8% in “paving” and 9.0% in “bare soil”. The remaining 19.7% of the trees were planted across four land cover categories.

Table 7.2: Percentage distribution of land cover categories for each tree species

Land cover categories	*Afrocarpus falcatus*	*Celtis africana*	*Combretum erythrophyllum*	*Harpephyllum caffrum*	*Kiggelaria africana*	*Olea europaea subsp. africana*	*Podocarpus* spp.	*Schotia brachypetala*	*Searsia lancea*	*Searsia pendulina*	*Senegalia galpinii*	*Vachellia karroo*	*Vachellia sieberiana* var.
Bare soil	_	13.2	16.2	_	_	28.2	_	_	9.0	41.1	_	_	_
Bare soil and paving	_	4.9	1.6	_	_	_	_	_	_	_	_	_	_
Bare soil and hard landscaping	–	0.5	2.7	–	–	–	–	–	–	–	–	–	–
Hard landscaping	_	1.4	1.1	_	_	_	_	_	5.5	_	_	_	_
Maintained lawn	_	60.6	54.5	_	_	49.8	_	100	43.0	51.7	51.2	100	_
Maintained lawn and paving	–	0.5	0.5	–	–	–	–	–	–	–	–	–	–
Maintained lawn plant bed	–	0.1	–	–	–	–	–	–	–	–	–	–	–
Maintained lawn and bare soil	50	–	–	–	–	6.2	100	–	–	–	–	–	–
Paving	_	3.9	3.0	_	100	11.5	_	_	9.8	_	_	_	_
Paving and hard landscaping	–	0.8	2.2	–	–	0.9	–	–	–	–	–	–	–
Paving and irrigation	_	_	2.6	90	_	_	_	_	_	_	_	_	_
Paving and plant bed	_	_	_	_	_	0.3	_	_	5.3	_	_	_	_
Plant bed	50	3.2	1.0	_	_	0.3	_	_	5.3	_	_	_	_
Plant bed and irrigation	–	–	0.1	10	–	–	–	–	4.0	–	–	–	–
Unmaintained grass	_	10.7	14.3	_	_	2.8	_	_	18.2	6.9	48.8	_	100
Total percentages	100	100	100	100	100	100	100	100	100	100	100	100	100

7.2.3 Distribution of maintenance needs for all the tree species

The results from the field survey reveal that (48.38%; n = 1 209) of the trees did not require any maintenance. Results for the remaining 51.62% (n = 1 290) are presented in Figure 7.5 indicating that 39% (n = 496) required coppice management and pruning and 30% (n = 388) required pruning where correction of the tree shape was required. The remaining 31% (n = 456) of the trees required 12 different categories of maintenance with less than 10% each.

Of the trees in the study requiring maintenance, 89% (n = 1 146) required some form of pruning and combinations of pruning and other maintenance needs, 46% (n = 595) required the removal of coppice combined with other maintenance needs, including pruning of coppice. These findings show that coppice and pruning was identified as the maintenance most required.

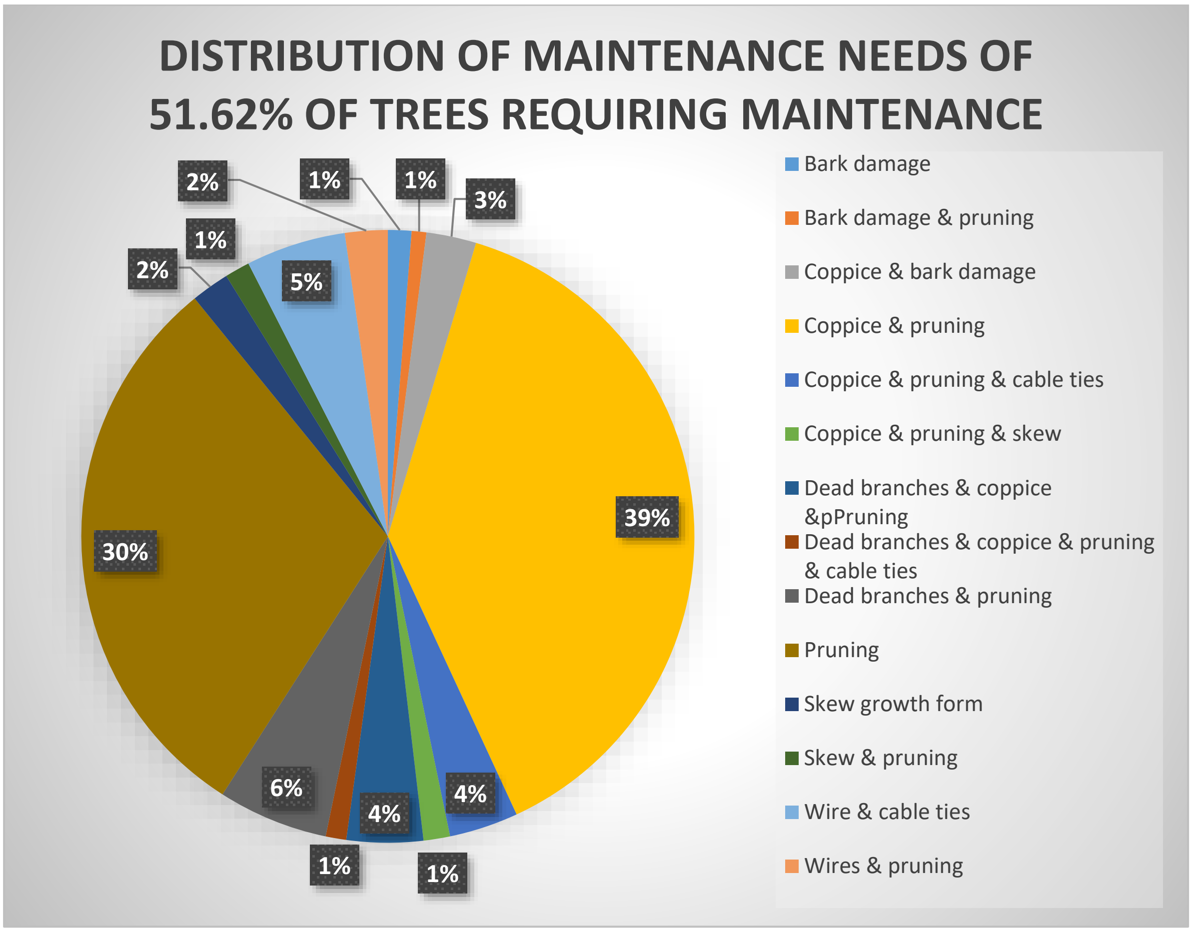


Figure 7.5: Distribution of maintenance categories of trees requiring maintenance

The results of the percentage distribution of the external factor category of maintenance needs for all the tree species in the study are presented in Table 7.3. The only species not requiring any maintenance was *V. karroo* and the species requiring the least maintenance were *A. falcatus* (27.5% of the trees in the study) and *S. galpinii* (31.7% of the trees in the study). *Celtis africana* required maintenance on 42% of the trees and more than 50% of all the other trees required maintenance - *Searsia lancea* (50%), *S. brachypetala* and *S. sieberiana* var. *woodii* (55%), *C. erythrophyllum* (62.5%), *O. europaea* subsp. *africana* (63.6%), *S. pendulina* (70.5%) and *H. caffrum* (80%). All the *K. africana* trees required maintenance (100%). The four tree species with the most trees measured in the study are described. The species with fewer than

50 trees in the sample did not provide noteworthy results as they were only found in one or two locations.

Table 7.3: Percentage distribution of maintenance needs of each tree species

Maintenance needs	*Afrocarpus falcatus*	*Celtis africana*	*Combretum erythrophyllum*	*Harpephyllum caffrum*	*Kiggelaria africana*	*Olea europaea subsp. africana*	*Podocarpus spp.*	*Schotia brachypetala*	*Searsia lancea*	*Searsia pendulina*	*Senegalia galpinii*	*Vachellia karroo*	*Vachellia sieberiana var. woodii*
Bark damage	_	_	0.4	_	_	0.6	_	_	_	_	_	_	_
Coppice and pruning	_	6.3	32.5	_	100	24.1	_	20.0	10.0	34.1	_	_	30.0
Coppice, pruning and bark damage	_	0.4	2.2	_	_	_	_	_	0.5	_	_	_	_
Coppice, pruning and skew growth	_	0.1	0.8	_	_	2.8	_	_	0.5	_	_	_	_
Coppice, pruning and wires or cable ties	_	4.1	1.1	_	_	0.6	_	_	0.3	_	_	_	_
Dead branches, coppice and pruning	_	1.3	1.9	_	_	4.4	_	_	1.1	15.9	_	_	_
Dead branches, coppice, pruning and wires or cable ties	_	_	0.6	_	_	0.9	_	_	_	6.8	_	_	_
Dead branches and pruning	_	5.2	2.0	_	_	2.8	_	_	0.5	13.6	_	_	_
No maintenance needs	72.5	58.0	38.5	20.0	_	36.4	50.0	45.0	50.0	29.5	68.3	100	45.0
Pruning (structural)	22.5	16.0	15.3	80.0	_	20.7	50.0	30.0	1.3	_	31.7	_	30.0
Pruning and bark damage	_	0.5	0.1	_	_	_	_	5.0	4.0	_	_	_	5.0
Pruning and skew growth form	_	0.2	1.1	_	_	1.3	_	_	1.1	_	_	_	_
Pruning and wires or cable ties	_	2.1	0.8	_	_	0.6	_	_	3.7	_	_	_	_
Skew growth form	_	0.6	1.0	_	_	2.2	_	_	25.9	_	_	_	_
Wires or cable ties around stems	5.0	5.1	1.5	_	_	2.5	_	_	1.1	_	_	_	_
Total percentage	100	100	100	100	100	100	100	100	100	100	100	100	100

The results of *C. africana* (Table 7.3) indicate that most of the trees (58%) did not require any maintenance. Of the remaining 42%, 36.3% required some form of pruning, 5.1% required the removal of wires and cable ties and 0.6% of the trees were growing skew and had to be straightened by tying the stems to a tree stake planted next to the stem.

The results of *C. erythrophyllum* (Table 7.3) show that 38.5% of the trees did not require any maintenance. Of the remaining 62.5%, 58.6% required some form of pruning, 46.3% had coppice present, 1.5% required the removal of wires and cable ties, 1.0% of the trees were growing skew and had to be straightened and 0.4% of the trees had bark damage that needed repair by cleaning the wounds and applying some form of tree sealing agent.

The results of *O. europaea* subsp. *africana* (Table 7.3) indicate that 36.4% of the trees did not require any maintenance. Of the remaining 63.6%, 58.3% required some form of pruning, 2.5% required the removal of wires and cable ties, 2.0% of the trees were growing skew and had to be straightened and 0.4% of the trees had bark damage that needed repair.

The results of *S. lancea* (Table 7.3) show that 50% of the trees did not require any maintenance and 25.9% of the trees were growing skew and had to be straightened. Of the remaining 24.1%, 23.0% required some form of pruning and 1.1% of the trees required the removal of wires and cable ties.

7.2.4 Distribution of pest and disease presence for all the tree species

Figure 7.6 shows that most of the trees (84.3%; n = 2 090) did not have any known pests or diseases visible to the naked eye present on the tree stem, branches or leaves and only 16% (n = 386) of the trees had insects, diseases or viruses present.

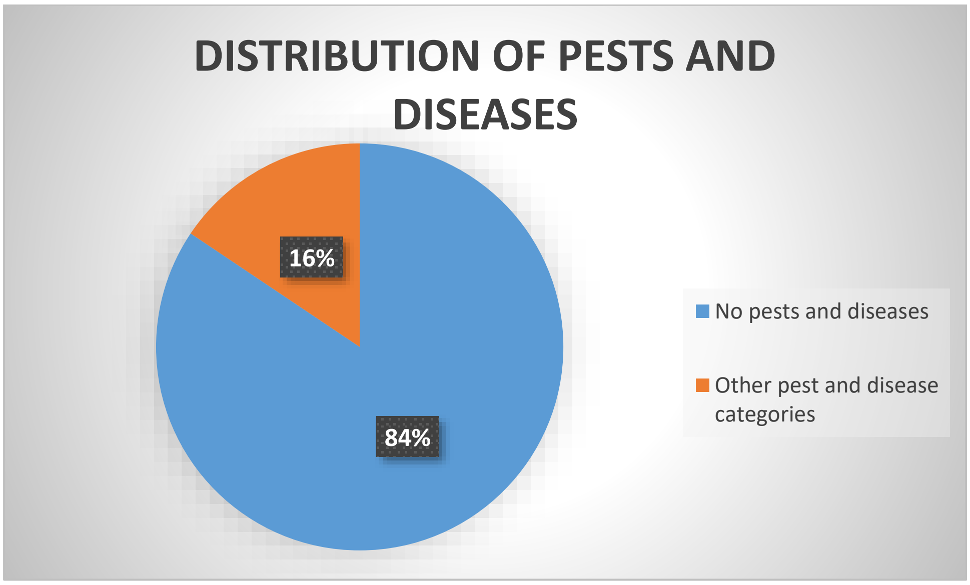


Figure 7.6: Distribution of pests and diseases for all the trees

The distribution of the trees with pests and diseases (16%) is shown in Figure 7.7. 56% (n = 216) of the trees were found with insects, 21% (n = 79) were found with insects and diseases and 14% (n = 52) were found with viruses. The remaining 9% (n = 39) trees were found in three categories. It must be noted that the presence of insects does not necessarily equate to pests. No presence of the polyphagous shot hole borer, also known as *Euwallacea fornicatus*, and the fungus (*Fusarium euwallaceae*) that grows in the tunnels made by the borer, was found.

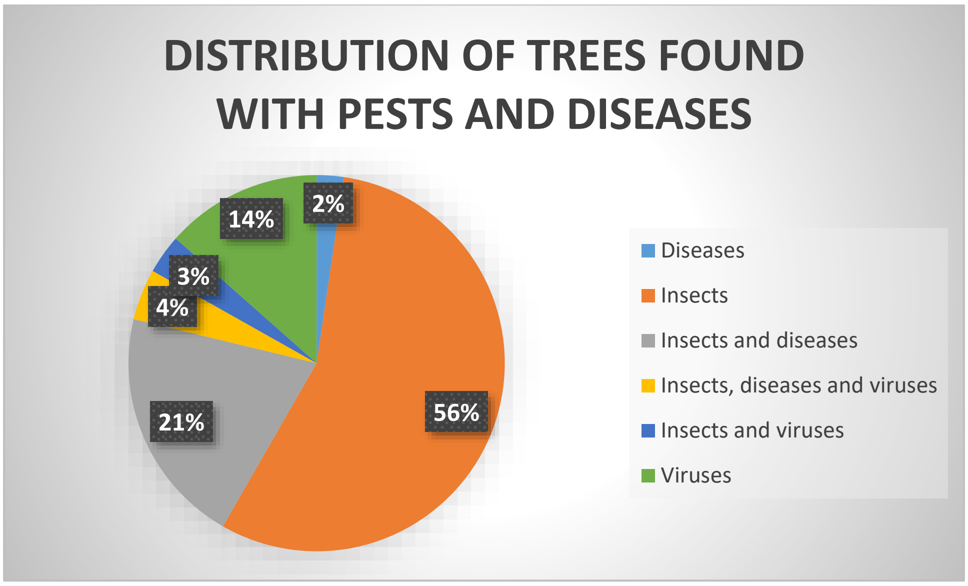


Figure 7.7: Distribution of pest and disease categories present

The percentage distribution of the pests and diseases category is shown in Table 7.4. The four tree species with the most trees in the study are discussed. The results of *C. africana* (Table 7.4) show that 82.2% of the trees did not have any visible pests and diseases, 11.8% had insects present, 3.8% had insects and diseases present, 1.1% had diseases 1.1% had viruses. The results of *C. erythrophyllum* (Table 7.4) show that 95.2% of the trees did not have any visible pests and diseases and the remaining 4.8% had insects present. The results of *O. europaea* subsp. *africana* (Table 7.4) reveal that 54.6% of the trees did not have any visible pests and diseases, 14.8% had insects and diseases present and another 14.8% had a virus. 6.0% had insects, diseases and a virus present, 5.3% had insects and the remaining 4.6% had insects and a virus. The results of *S. lancea* (Table 7.4) show that 88.7% of the trees did not have any visible pests and diseases, 10.0% of the trees had insects present and the remaining 1.3% had insects and diseases. No pests and diseases were found on any of the *S. galpinii, V. karroo, V. sieberiana* var. *woodii*, *S. brachypetala* and *S. pendulina* species.

Table 7.4: Percentage distribution of pests and diseases present for each tree species

Pests and diseases	*Afrocarpus falcatus*	*Celtis africana*	*Combretum erythrophyllum*	*Harpephyllum caffrum*	*Kiggelaria africana*	*Olea europaea subsp. africana*	*Podocarpus* spp.	*Schotia brachypetala*	*Searsia lancea*	*Searsia pendulina*	*Senegalia galpinii*	*Vachellia karroo*	*Vachellia sieberiana* var.
Diseases	_	1.1	_	_	_	_	_	_	_	_	_	_	_
Insects	12.5	11.8	4.8	90.0	100	5.3	_	_	10.0	_	_	_	_
Insects and diseases	_	3.8	_	_	_	14.8	_	_	1.3	_	_	_	_
Insects, diseases and viruses	_	_	_	_	_	6.0	_	_	_	_	_	_	_
Insects and viruses	_	_	_	_	_	4.6	_	_		_	_	_	_
No pests and diseases	87.5	82.2	95.2	10.0	_	54.6	_	100	88.7	100	100	100	100
Virus	_	1.1	_	_	_	14.8	_	_	_	_	_	_	_
Total percentage	100	100	100	100	100	100	100	100	100	100	100	100	100

7.2.5 Distribution of impact of human influence for all the tree species

The results of the impact of human influence on the trees in the study indicate that 55% (n = 1 378) of the trees were planted in maintained environments, with regularly mowed grass or maintained flowerbeds surrounding the trees. Of the remaining 45% trees (n = 1 127) (Figure 7.8), 43% (n = 487) were found in unmaintained areas, 18% (n = 202) in areas with pedestrian traffic in a maintained area, 11% (n = 126) in areas with pedestrian traffic and 10% (n = 112) in areas with pedestrian traffic in unmaintained areas. The remaining 18% of the trees were found in seven different human influence categories, at less than 10%.

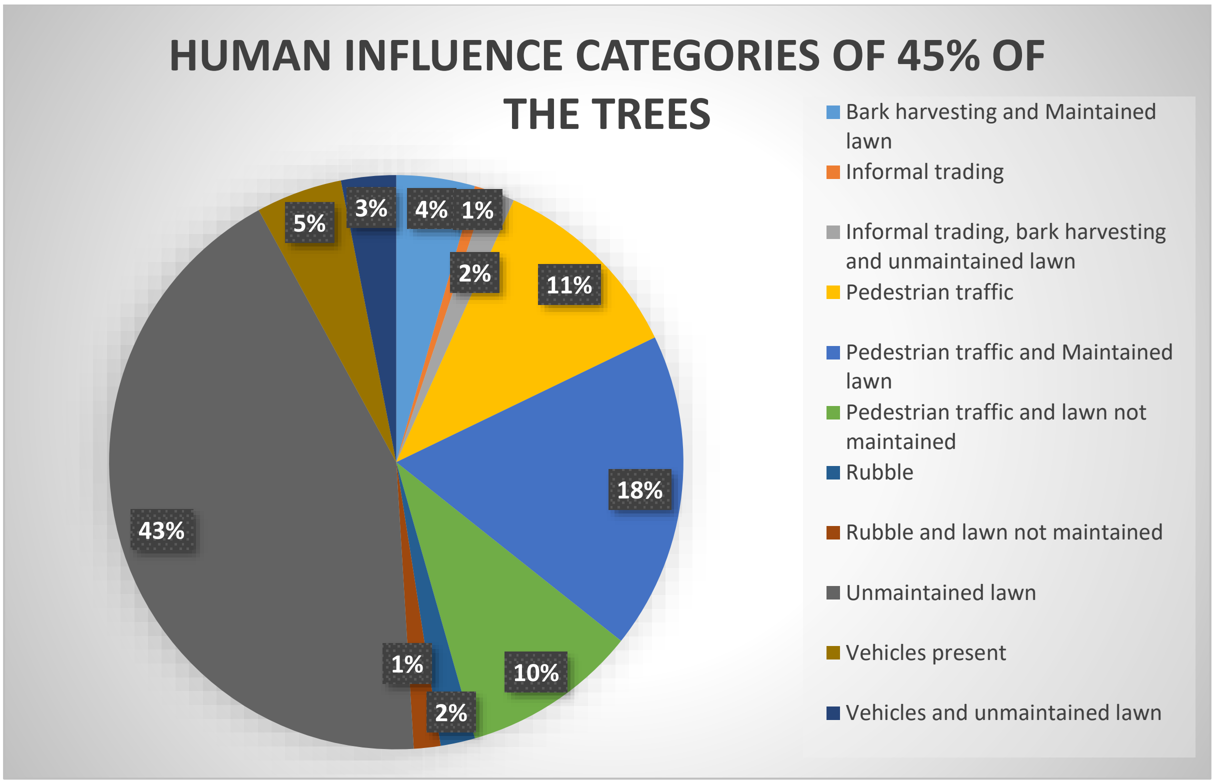


Figure 7.8: Distribution of human influence categories

The percentage distribution of the human influence external factor category for the tree species in the study is presented in Table 7.5. The four tree species with the most trees measured in the study are discussed. For *C. africana* (Table 7.5), 78.1% of the trees were found in maintained areas, 39.2% in maintained lawn and 38.9% in unmaintained lawn. The "pedestrian traffic and lawn not maintained" category consisted of 5.8% of the trees and 5.6% were found in the "vehicles present" category. The remaining 11.5% of the trees were found at less than 4% across six other human influence categories. For *C. erythrophyllum* (Table 7.5), 73.6% of the trees were found in areas where maintenance of lawn may affect the growth of the trees. 39.0% were found in maintained lawn and 34.6% in unmaintained lawn. 9.2% were in the "bark harvesting and maintained lawn" category and 5.5% in the "rubble and maintained lawn" category. The remaining 10.8% of the trees were found across seven other human influence categories at less than 4%. 21.1% of *O. europaea* subsp. *africana* (Table 7.5) were found in the human influence category "maintained lawn", 20.5% in the "pedestrian traffic and unmaintained lawn" category, 13.0% in "unmaintained lawn", 12.4% in "pedestrian traffic" and 11.8% in the "rubble and unmaintained lawn" category. 10.5% of the trees were found in the human influence category "bark harvesting and unmaintained lawn", 9.9% in "informal trading" and 5.6% in "vehicles present". The remaining 5.5% of the trees were found across five other human influence categories at less than 4%. For *S. lancea* (Table 7.5), 70.9% of the trees were found in "maintained lawn" areas, 58.0% in "maintained lawn", 14.0% in “pedestrian traffic and maintained lawn” and 12.9% in “unmaintained lawn”. The remaining 7.9% of the trees were found across four other human influence categories at less than 5%.

Table 7.5: Percentage distribution of human influence surrounding all the trees

Human influence	*Afrocarpus falcatus*	*Celtis africana*	*Combretum erythrophyllum*	*Harpephyllum caffrum*	*Kiggelaria africana*	*Olea europaea subsp. africana*	*Podocarpus* spp.	*Schotia brachypetala*	*Searsia lancea*	*Searsia pendulina*	*Senegalia galpinii*	*Vachellia karroo*	*Vachellia sieberiana var. woodii*
Bark harvesting and maintained lawn	–	–	9.2	–	–	10.5	100	–	–	10.3	–	–	–
Informal trading	–	0.8	–	–	–	9.9	–	–	–	–	–	–	–
Informal trading, bark harvesting and unmaintained lawn	–	–	0.4	–	–	–	–	–	–	–	–	–	–
Maintained lawn	100	39.2	39.0	100	–	21.1	–	100	58.0	48.3	51.2	66.6	100
Pedestrian traffic	–	–	–	–	–	12.4	–	–	–	–	–	33.3	–
Pedestrian traffic and maintained lawn	–	–	–	–	100	0.6	–		14	–	–	–	–
Pedestrian traffic and lawn not maintained	–	5.8	0.4	–	–	20.5	–	–	1.7	–	–	–	–
Rubble	–	0.6	0.7	–	–	1.2	–	–	0.3	–	–	–	–
Rubble and maintained lawn	–	0.6	5.4	–	–	3.6	–	–	–	–	–	–	–
Rubble and lawn not maintained	–	2.8	0.2	–	–	11.8	–	–	–	3.4	–	–	–
Unmaintained lawn	–	38.9	34.6	–	–	13.0	–	–	12.9	37.9	48.8	–	–
Vehicles present	–	5.6	3.9	–	–	5.6	–	–	–	–	–	–	–
Vehicles and unmaintained lawn	–	4.9	–	–	–	–	–	–	4.5	–	–	–	–
Total percentage	100	100	100	100	100	100	100	100	100	100	100	100	100

7.2.6 Distribution of conflict caused by the tree species

The results of the conflict caused by the tree species in the study to existing infrastructure (Figure 7.9) show that for 85% (n = 2 159) of the trees, the surrounding area did not present any conflict or the trees did not cause any damage to the infrastructure. For the remaining 15%, there was conflict with the road (5%; n = 128) and interference with overhead structures (5%; n = 124) and damage was caused to the paving surrounding the tree (3%; n = 85) and the sidewalk (1%; n = 35).

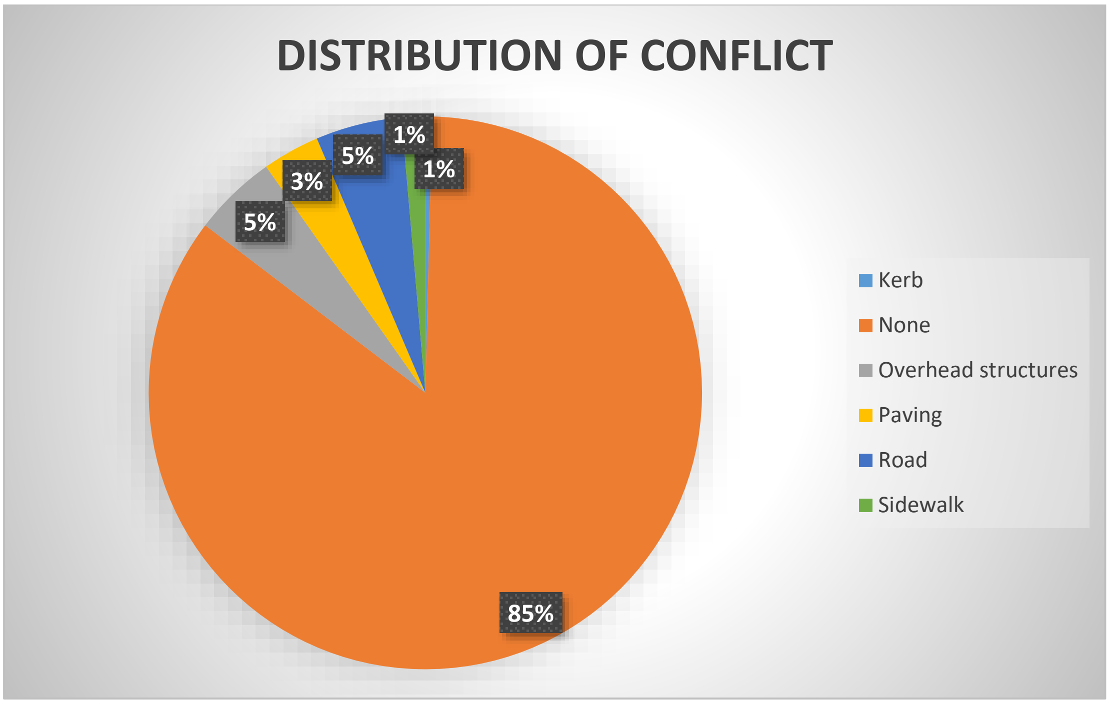


Figure 7.9: Presence of conflict with infrastructure surrounding the trees

The percentage distribution of the conflict of trees in the study is presented in Table 7.6. The four tree species with the most trees measured in the study are discussed. The results of *C. africana* (Table 7.6) show that 81.6% of the trees were not in any conflict, 7.8% of the trees were found where the road was in conflict, 7.5% where overhead structures were in conflict, 2.5% where the sidewalk was in conflict and 0.6% where paving was in conflict.For *C. erythrophyllum* (Table 7.6), 85.5% of the trees were not in any conflict, 8.1% were in conflict with overhead structures, 3.5% with the kerb and 2.9% with the road. 85.0% of *O. europaea subsp. africana* (Table 7.6) trees were not in any conflict, 6.0% were in conflict with the road, 5.2% were in conflict with paving, 3.4% with overhead structures and 0.4% with the kerb.The results of *S. lancea* (Table 7.6) depict that 96.2% of the trees were not in any conflict and 3.8% were in conflict with overhead structures.

Table 7.6: Percentage distribution of conflict

Conflict	*Afrocarpus falcatus*	*Celtis africana*	*Combretum erythrophyllum*	*Harpephyllum caffrum*	*Kiggelaria africana*	*Olea europaea subsp. africana*	*Podocarpus* spp.	*Schotia brachypetala*	*Searsia lancea*	*Searsia pendulina*	*Senegalia galpinii*	*Vachellia karroo*	*Vachellia sieberiana var. woodii*
Kerb	–		3.5	–	–	0.4	–	–	–	31.3	–	–	–
No conflict	100	81.6	85.5	100	100	85.0	100	100	96.2	37.9	100	66.6	100
Overhead structures	–	7.5	8.1	–	–	3.4	–	–	3.8	27.6	–	–	–
Paving	–	0.6	–	–	–	5.2	–	–	–	–	–	33.3	–
Road	–	7.8	2.9	–	–	6.0	–	–	–	–	–	–	–
Sidewalk	–	2.5	–	–	–	–	–	–	–	–	–	–	–

7.2.7 Summary of distribution of land cover, land use and external factors

As discussed in previous chapters, approximately two-thirds of the trees in the tree planting project were planted as street trees on sidewalks and medians and one-third in parks. However, this part of the study provided additional analysis of the land uses of the sidewalks and medians. Most of the trees on sidewalks and medians were found in formal residential land use areas, with maintained lawn land cover and were not in any conflict with or damaging infrastructure. The trees in this study have not yet reached a mature height and may be in conflict in future when they grow to a mature height without being pruned. The trees in parks were planted mostly in maintained lawn where the surrounding lawns were regularly mowed and the flowerbeds were maintained. Most of the trees did not have any pests or diseases visible to the naked eye on the stems, branches or leaves. Most of the trees in parks were planted in an area where they or the surrounding area were not in conflict, or the trees did not cause any damage to infrastructure. More than half of the trees in both parks and streets required some form of maintenance and a large percentage of these trees required some form of pruning, including the removal of coppice growth.

7.3 Distribution of land use and land cover for the missing trees

To determine if any of the land uses or land covers negatively affected the survival of the trees in the study, data was analysed for the distribution of land use and land cover categories of the missing trees. The missing trees (n = 410) were identified in Chapter 4 of this study, in section 4.3.5. The results are provided for each of the different categories of missing trees in Tables 7.7 to 7.16. In this section, some of the land use and land cover categories were consolidated to eliminate combinations of land use and land cover areas not contributing to the results. The consolidation involved simplifying the land use areas into a single land use or land cover.

The land use areas were consolidated as follows: “commercial and education”, “commercial and median” and “commercial and vacant land” were consolidated into “commercial”. “Formal residential and vacant land”, “formal residential and commercial”, “formal residential and sport or park”, “formal residential and industrial”, “formal residential and education”, “formal residential and median” and “formal residential and government” were consolidated into “formal residential”. “Industrial and open space maintained” and “formal residential and open space maintained” were consolidate into “open space maintained”.

The land cover categories were consolidated as follows: “Maintained lawn and bare soil”, “maintained lawn and plant bed” and “maintained grass and paving” were consolidated into “maintained lawn”. “Paving and hard landscaping”, “paving and irrigation” and “paving and plant bed” were consolidated into “paving”. “Plant bed” and “Plant bed and irrigation” were consolidated into “plant bed”, and “bare soil and paving” and “bare soil and hard landscaping” were consolidated into “bare soil”.

7.3.1 Dead trees

The results for the distribution of land use (Table 7.7) and land cover (Table 7.8) for the dead trees (n = 44) indicate that 36.3% were found in the “park” land use and 34.1% in the “vacant land” land use. 84.1% of the dead trees were found in the “maintained lawn” land cover category. No dead trees were found in the “industrial”, “religious”, “education” and “government” land use categories.

Table 7.7: Distribution of land use for dead trees

Land use	*Celtis africana*	*Combretum erythrophyllum*	*Olea europaea* subsp. *africana*	*Searsia lancea*	*Vachellia sieberiana* var. *woodii*
Commercial	_	_	_	_	1
Formal residential	–	–	3	4	–
Informal residential	1	–	–	–	–
Open space maintained	–	–	3	2	–
Park	1	5	4	5	_
Vacant land	15	_	_	_	_
TOTAL	17	5	10	11	1

Table 7.8: Distribution of land cover for dead trees

Land cover	*Celtis africana*	*Combretum erythrophyllum*	*Olea europaea* subsp. *africana*	*Searsia lancea*	*Vachellia sieberiana* var. *woodii*
Maintained lawn	15	5	5	11	1
Paving		_	5	_	_
Unmaintained lawn	2	_	_	_	_
TOTAL	17	5	10	11	1

7.3.2 Absent trees

The results for the distribution of land use (Table 7.9) and land cover (Table 7.10) for the absent trees (n = 115) reveal that 38.2% were found in the “formal residential” land use, followed by 16.5% in the “vacant land” and 11.4% each in the “informal residential” and “park” land uses. 33.9% of the dead trees were found in the “bare soil” land cover category, 26.1% in “unmaintained lawn” and 23.4% in “maintained lawn”. No dead trees were found in the “plant bed” land cover areas.

Table 7.9: Distribution of land use for absent trees

Land use	*Afrocarpus falcatus*	*Celtis africana*	*Combretum erythrophyllum*	*Kiggelaria africana*	*Olea europaea subsp. africana*	*Searsia lancea*	*Searsia pendulina*	*Senegalia galpinii*
Commercial	_	_	2	_	2	4	_	1
Formal residential	3	5	3	5	21	7	_	_
Industrial	_	1	4	_	_	1	_	_
Informal residential	_	_	4	_	9	_	_	_
Open space maintained	3	_	3	_	_	_	5	_
Park	_	_	_	_	2	11	_	_
Vacant land	_	9	_	_	_	10	_	_
TOTAL	6	15	16	5	34	34	5	1

Table 7.10: Distribution of land cover for absent trees

Land cover	*Senegalia galpinii*	*Celtis africana*	*Combretum erythrophyllum*	*Kiggelaria africana*	*Olea europaea subsp. africana*	*Afrocarpus falcatus*	*Searsia lancea*	*Searsia pendulina*
Bare soil	_	5	2	_	16	_	13	3
Hard landscaping	_	_	_	_	_	_	5	_
Maintained lawn	1	7	3	_	2	3	9	2
Paving	_	_	_	5	_	_	_	_
Plant bed	_	_	7	_	_	3	_	_
Unmaintained lawn	_	3	4	_	16	_	7	_
TOTAL	1	15	16	5	34	6	34	5

7.3.3 Coppice

The results for the distribution of land use (Table 7.11) and land cover (Table 7.12) for the trees with coppice only (n = 216) indicate that 29.6% of the trees with coppice were found in the "formal residential" land use category, followed by 23.1% in "park" and 17.6% in "open space maintained". No trees with coppice only were found in the "religious" land use area. 65% of the trees with coppice only were found in the "maintained lawn" land cover category and 29.6% were found in the "bare soil" land cover category.

Table 7.11: Distribution of land use for trees with coppice only

Land use	*Celtis africana*	*Combretum erythrophyllum*	*Olea europaea* subsp. *africana*	*Podocarpus* spp.	*Searsia lancea*	*Searsia pendulina*	*Vachellia sieberiana* var. *woodii*
Commercial	3		8		20	_	2
Formal residential	8	52	6	_	2	6	_
Open space maintained	1	17	_	_	_	20	_
Park	_	37	_	2	11	_	_
Vacant land	6	8	_	_	_	11	_
TOTAL	15	109	14	2	33	37	2

Table 7.12: Distribution of land cover for trees with coppice only

Land cover	*Celtis africana*	*Combretum erythrophyllum*	*Olea europaea* subsp. *africana*	*Podocarpus* spp.	*Searsia lancea*	*Searsia pendulina*	*Vachellia sieberiana* var. *woodii*
Hard landscaping	_	1	_	_	_	_	_
Maintained lawn	3	66	_	2	11	20	2
Paving	_	5	_	_	1	_	_
Bare soil	12	12	14	_	20	6	_
Unmaintained lawn	_	25	_	_	1	11	_
TOTAL	15	109	14	2	33	37	2

7.3.4 Tree stump with coppice

The results for the distribution of land use (Table 7.13) and land cover (Table 7.14) for tree stump with coppice (n = 27) indicate that 33.3% of the tree stumps with coppice were found in the "formal residential" land use category and 29.6% in "open space maintained". No tree stumps with coppice were found in the “informal residential”, “religious”, “government” and “education” land uses. 48.1% were found in the “bare soil” land cover category and 25.9% in “maintained lawn”. No trees with coppice only were found in the “hard landscaping” and “plant bed” land cover areas.

Table 7.13: Distribution of land use for stump with coppice

Land use	*Celtis africana*	*Combretum erythrophyllum*	*Olea europaea subsp. africana*	*Searsia lancea*	*Searsia pendulina*
Commercial	_		_	3	_
Formal residential	2	5	2	_	_
Industrial	_	1	_		_
Open space maintained	_	_	5	1	2
Park	1	2	_	1	_
Vacant land	_	_	1	1	_
TOTAL	3	8	8	6	2

Table 7.14: Distribution of land cover for stump with coppice

Land cover	*Celtis africana*	*Combretum erythrophyllum*	*Olea europaea subsp. africana*	*Searsia lancea*	*Searsia pendulina*
Maintained lawn	2	2	_	1	2
Paving	1	_	_	1	_
Bare soil	_	3	8	2	_
Unmaintained lawn	_	3	_	2	_
TOTAL	3	8	8	6	2

7.3.5 Dead stumps

The results for the distribution of land use (Table 7.15) and land cover (Table 7.16) for the dead stumps (n = 10) indicate that 50% of the dead stumps were found in the “park” land use category and 70% in the “maintained lawn” land cover category. No dead stumps were found in the “commercial”, “religious”, “education” and “government” land use areas or in the “unmaintained lawn”, “hard landscaping” and “plant bed” land cover areas.

Table 7.15: Distribution of land use for dead stumps

Land use	*Celtis africana*	*Combretum erythrophyllum*	*Olea europaea subsp. africana*	*Schotia brachypetala*	*Searsia lancea*	*Searsia pendulina*
Formal residential	1	_	_	_	_	1
Industrial	_	_	_		2	_
Open space maintained	_	_	_	1	_	_
Park	_	4	1	_	_	_
TOTAL	1	4	1	1	2	1

Table 7.16: Distribution of land cover for dead stumps

Land cover	*Celtis africana*	*Combretum erythrophyllum*	*Olea europaea* subsp. *africana*	*Schotia brachypetala*	*Searsia lancea*	*Searsia pendulina*
Bare soil	_	_	_	_	2	1
Maintained lawn	1	4	1	1	_	_
TOTAL	1	4	1	1	2	1

In summary, most of the missing trees in the study were found in the "park" land use category, followed closely by the "formal residential" category. A noticeable number of missing trees were found in the "vacant land" and the "open space maintained" land use categories, with a small number of missing trees in the "informal residential" land use category. Most of the missing trees were found in the "maintained lawn" land cover category, followed by "bare soil" and a small number in "unmaintained".

7.4 The impact of land use, land cover and external factors on tree growth

The percentage distribution of land use, land cover and the external factors for the *C. africana, C. erythrophyllum, S. lancea* and *O. europaea* subsp*. africana* trees, per region, is presented. To determine whether the land use, land cover or any of the external factors had an impact on the growth of the trees, the stem circumference measurements or CGL of the trees were analysed and the mean ages of the trees were identified per tree, per category. The CGL and age results are provided for these categories with more than 10% of the trees per species. Maps of the locations of each species are included to provide a visual representation of the distribution of the trees in each region. The maps show the trees in different colours, according to land use, land cover and external factor on the site where they were found.

7.4.1 The impact of land use per species per region

The distribution of land use categories for each species is presented per region and thereafter for the mean circumference of each of the trees in the different regions, with the aim to determine if land use in a specific region had an impact on tree growth. The age of the youngest tree (minimum age) and the oldest tree (maximum age) and the mean age of the trees in each land use area are presented to enable comparisons.

7.4.1.1 Celtis africana

The results of the distribution of land use categories for *C. africana* (Table 7.17 and Figure 7.10) indicate that 100% of the *C. africana* trees in Regions A and F were found in the "formal residential" land use and in Region B, 100% were found in the "commercial and education" category. In Region C they were found in the "formal residential" (33.2%) land use category, followed by "parks" (19.6%) and "vacant land" (19.2%). The remainder of the trees (28%) were found in combinations of land uses such as "commercial and vacant land" and "formal residential and vacant land". In Region D, 26.9% of the *C. africana* trees were found in the "park" land use category, followed by "formal residential" (10.6%), "education" (9.6%) and "government" (9.4%).

Table 7.17: Percentage distribution of land use categories for Celtis africana

Land use categories for *Celtis africana*	**Region A**	**Region B**	**Region C**	**Region D**	**Region F**
Commercial	_	_	4.2	2.8	_
Commercial and education	_	100	_	_	_
Commercial and median	_	_	1.4	6.4	_
Commercial and vacant land	_	_	9.3	_	_
Education	_	_	_	9.6	_
Education and median	_	_		6.6	_
Formal residential	_	_	33.2	10.6	100.0
Formal residential and commercial	100	_	_	_	_
Formal residential and education	_	_	_	2.8	_
Formal residential and industrial	_	_	2.3	_	_
Formal residential, industrial and median	_	_	1.4	2.2	_
Formal residential and median	_	_	_	2.0	_
Formal residential and vacant land	_	_	8.4	_	_
Government	_	_	_	9.4	_
Industrial	_	_	_	4.0	_
Industrial and open space maintained	_	_	0.9	_	_
Informal residential and median	_	_	_	7.6	_
Informal residential	_	_	_	2.0	_
Maintained open space	_	_		4.2	_
Park	_	_	19.6	26.9	_
Vacant land	_	_	19.2	2.2	_
Vacant land and median	_	_	_	0.4	_
Total percentage	100	100	100	100	100

Figure 7.10 illustrates the distribution of the *C. africana* trees in the study (Region A (n = 21); Region B (n = 9); Region C (n = 231); Region D (n = 496); Region F (n = 19)) and the land uses of the trees are indicated in different colours and listed in the legend of the figure. The large number of *C. africana* trees is visible in Region D. Note that the trees seen in Region E

in this figure were allocated to Region A in the study as the region boundaries were changed subsequent to the survey conducted in this study.

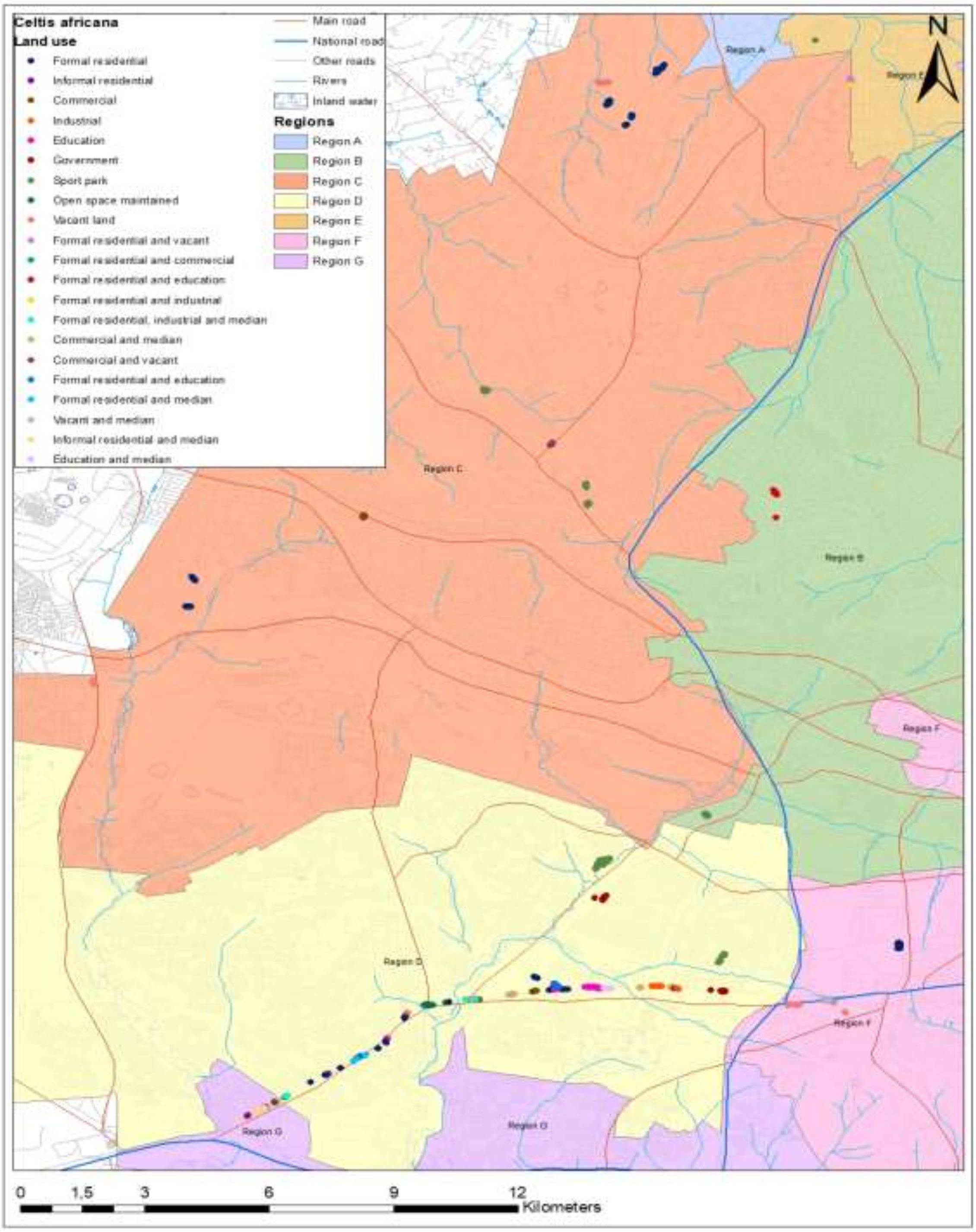


Figure 7.10: Land use of Celtis africana *per region*

The results for the mean circumference measurement (CGL) and age of the *C. africana* trees in the different land use categories for each region (Table 7.18) show that the trees with the widest mean CGL (858.9 mm) were in the “formal residential” land use category in Region F with a mean age of 14 years. The trees with the smallest mean CGL (390.76 mm) were in the “formal residential and commercial” land use category in Region A and the trees were 12 years old. The trees in Region C (mean CGL of 612.62 mm) and Region D (mean CGL of 606.48 mm), both found in the “formal residential” category, were the youngest (12 years). The oldest trees (16 years) were found in Region C in the “formal residential” land use (mean CGL of 612.62 mm).

Table 7.18: Mean CGL and age per land use category for Celtis africana

Region	Land use category	Mean CGL per category (mm)	Minimum and maximum ages (years)	Mean age (years)
Region A	Formal residential and commercial	390.76	12	12
Region B	Commercial and education	426.66	13	13
Region C	Formal residential	612.62	12 to 16	15
	Park	631.39	13 and 15	15
	Vacant land	423.65	13	13
Region D	Formal residential	606.48	12 and 15	14
	Park	485.09	14 and 15	15
Region F	Formal residential	858.90	14	14

7.4.1.2 Combretum erythrophyllum

The results of the distribution of land use categories for *C. erythrophyllum* (Table 7.19), visible in Figure 7.11, indicate that in Region A, 54.5% of the trees were found in the “formal residential and vacant land” and 45.5% in the “vacant land” categories. In Region B, 55.6% were found in the “park” category and 44.1% in “formal residential and sport or park”. In Region F, the land use distribution was spread equally (50%) over two land uses, namely “formal residential” and “maintained open space”. In Region C, 43.7% of the trees were found in “formal residential”, followed by 17.6% in “park” and 15.1% in “commercial”. In Region D, 69.8% were found in the “park” land use, followed by 18.3% in “formal residential and median”. The remaining 12% were found in three categories.

Table 7.19: Percentage distribution of land use categories for Combretum erythrophyllum

Land use category for *Combretum erythrophyllum*	**Region A**	**Region B**	**Region C**	**Region D**	**Region F**
Commercial	_	_	15.1	_	_
Education	_	_	0.7	_	_
Formal residential	_	_	43.7	_	50.0
Formal residential and education	_	_	_	3.9	_
Formal residential and government	_	_	_	2.1	_
Formal residential and median	_	_	_	18.3	_
Formal residential and vacant land	54.5	_	3.5	_	_
Formal residential and sport or park	_	44.1	_	_	_
Industrial	_	_	7.4	_	_
Maintained open space	_	_	2.1	6.0	50.0
Park	_	55.6	17.6	69.8	_
Vacant land	45.5	_	9.9	_	_
Total percentage	100	100	100	100	100

Figure 7.11 displays the distribution of the *C. erythrophyllum* trees in the study (Region A (n = 26); Region B (n = 36); Region C (n = 282); Region D (n = 348) and Region F (n = 40)) and the land uses of the trees are indicated in different colours and listed in the legend of the figure. The *C. erythrophyllum* trees are spread across all regions. The trees seen in Regions E and G in this figure were allocated to Regions A and D, respectively, in the study as the boundaries of the regions were reorganised subsequent to the survey part of this study.

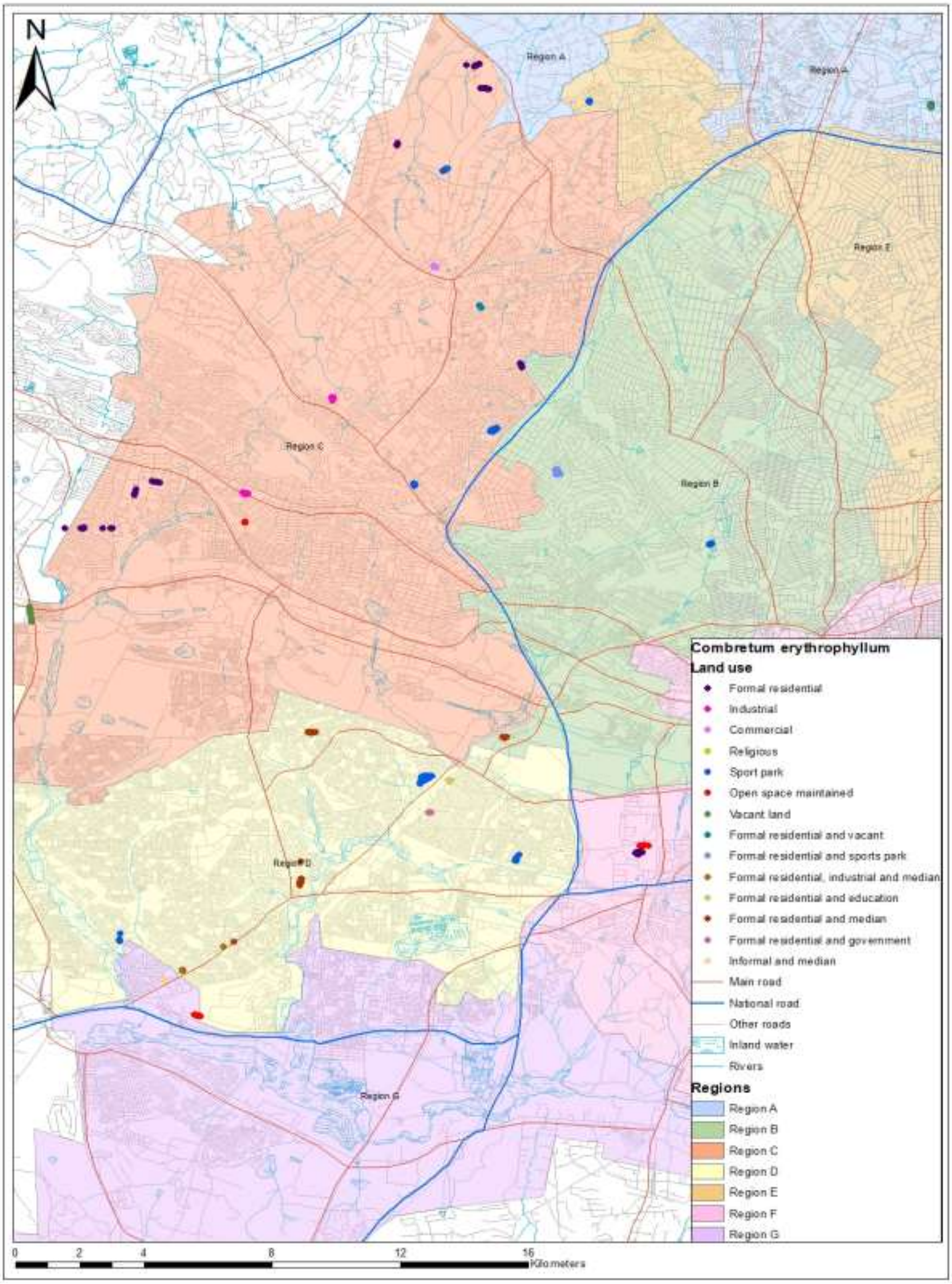


Figure 7.11: Land use of Combretum erythrophyllum *per region*

The results for the mean CGL and age of the *C. erythrophyllum* trees in the different land use categories for each region (Table 7.20) indicate that the trees with the widest mean CGL

(791.5 mm) were in the “formal residential” land use category in Region F with a mean age of 14 years. The trees with the smallest mean CGL (161.9 mm) were in the “vacant land” category in Region A with a mean age of 12 years. The youngest trees (12 years) were found in Region A in the “formal residential and vacant land” category with a mean CGL of 229.83 mm and in the “vacant land” category with a mean CGL of 161.9 mm. The oldest trees (16 years) were found in Region D in the “formal residential and median” category (mean CGL of 433.30 mm).

Table 7.20: Mean CGL and age per land use category for Combretum erythrophyllum

Region	**Land use category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region A	Formal residential and vacant land	229.83	12	12
	Vacant land	161.90	12	12
Region B	Formal residential and park	382.51	13	13
	Park	262.25	13	13
Region C	Commercial	422.99	13 and 15	14
	Formal residential	496.01	13 and 16	15
	Park	501.61	14 and 15	14
Region D	Formal residential and median	433.30	9 and 16	12
	Park	487.04	10 and 15	14
Region F	Formal residential	791.50	14	14
	Maintained open space	351.85	14	14

7.4.1.3 Olea europaea subsp. *africana*

The results of the distribution of land use categories for *O. europaea* subsp. *africana* (Table 7.21), visible in Figure 7.12, indicate that none of this species were found in Regions A and B. In Region C, 53.1% of the trees were found in the “formal residential”, 18.8% in the “park” and 17.5% in the “commercial” land use categories. The remainder of the trees (11.6%) were found in small percentages in a range of land uses. Of the *O. europaea* subsp. *africana* trees in Region D, 64.0% were found in the “park” and 20.5% in the “formal residential and median” land use categories. In Region F, all the trees were found in the “maintained open space” category.

Table 7.21: Percentage distribution of land use categories for Olea europaea subsp. africana

Land use category for *Olea europaea subsp. africana*	**Region C**	**Region D**	**Region F**
Commercial	17.5	_	_
Commercial and median	3.8	_	_
Formal residential	53.1	5.6	_
Formal residential and commercial	1.3	_	_
Formal residential and education	_	9.9	_
Formal residential and median	_	20.5	_
Formal residential and vacant land	3.8	_	_
Informal residential	1.9	_	_
Maintained open space	_	_	100
Park	18.8	64.0	_
Vacant land	_	5.6	_
Total percentage	100	100	100

Figure 7.12 displays the distribution of the *O. europaea* subsp. *africana* trees in the study (Region A (n = 0); Region B (n = 0); Region C (n = 162); Region D (n = 165) and Region F (n = 20)) and the land uses of the trees are indicated in different colours and listed in the legend of the figure. These trees are spread across three of the regions (C, D and F) in the study, with none of these species found in Regions A and B.

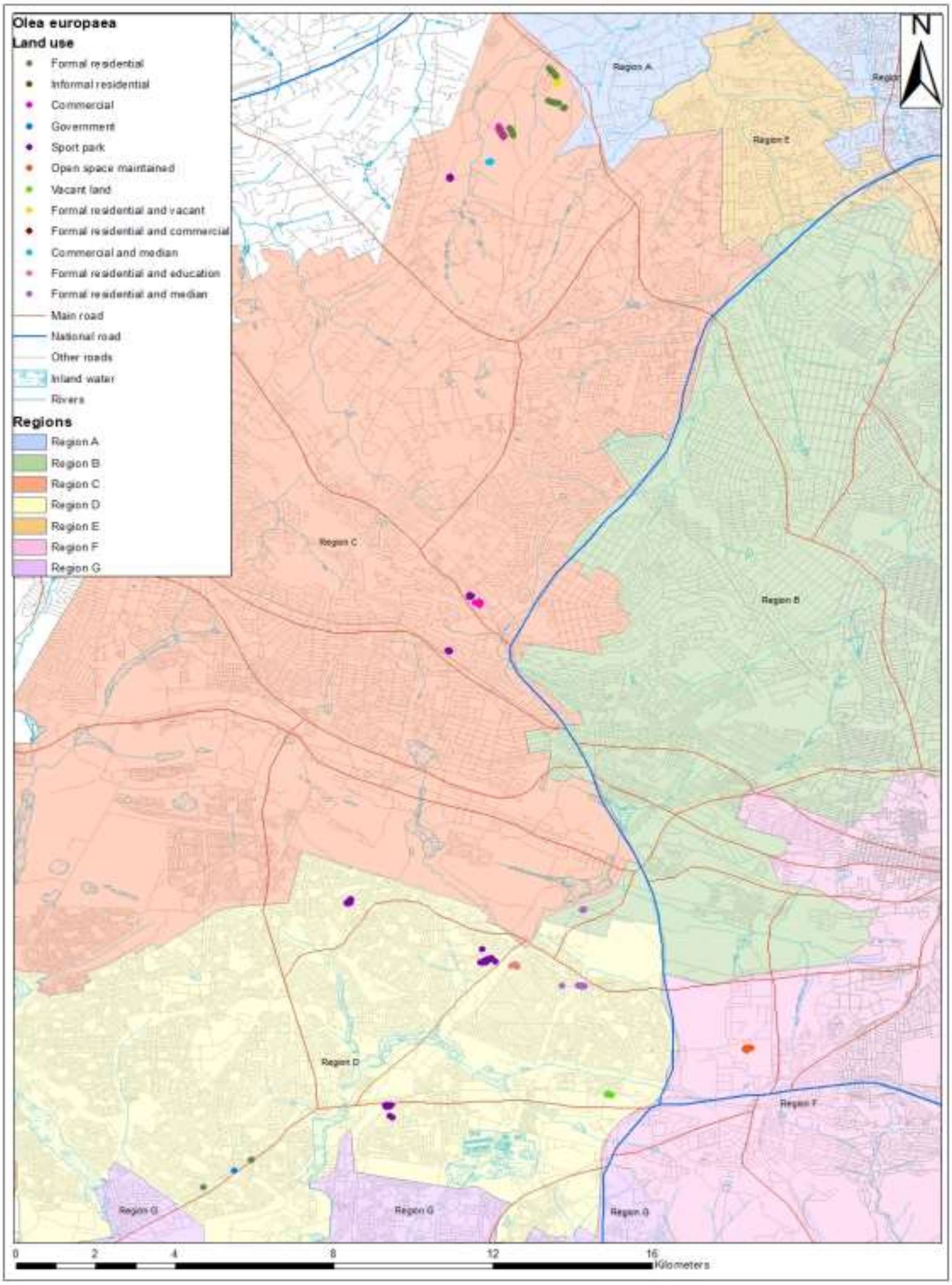


Figure 7.12: Land use of Olea europaea subsp. africana *per region*

The results for the mean CGL and age of the *O. europaea* subsp. *africana* trees in the different land use categories for each region (Table 7.22) indicate that the trees with the widest mean CGL (509.75 mm) were in the "formal residential" land use category in Region C with a mean age of 15 years. The trees with the smallest mean CGL (161.9 mm) were found in the "open space maintained” category in Region F with a mean age of 16 years. The youngest trees (14 years) were found in the “commercial” category in Region C, with a mean CGL of 358.96 mm, and in the “park” category in Region D, with a mean CGL of 287.44 mm. The oldest trees (16 years) were found in the “park” category with a mean CGL of 478.01 mm.

Table 7.22: Mean CGL and age per land use category for Olea europaea subsp. africana

Region	**Land use category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region C	Commercial	358.96	14	14
	Formal residential	509.75	14 and 16	15
	Park	478.01	15 and 16	16
Region D	Formal residential and median	346.27	13 and 16	15
	Park	287.44	12 and 16	14
Region F	Open space maintained	275.15	16	16

7.4.1.4 Searsia lancea

The results of the distribution of land use categories for *S. lancea* (Table 7.23), displayed in Figure 7.13, show that in Region A, 80% of the trees were found in the “formal residential” category and 20% in the “park” category. No *S. lancea* trees were found in Region B. The *S. lancea* trees in Region C were found in the “formal residential” (45.9%) land use category, followed by “commercial” (27%), “park” (17.5%) and “vacant land” (10.7%). In Region D, 33.3% each were found in the “park” and “formal residential and median” categories and 16.7% each in the “commercial and median” and “formal residential and open space maintained” categories. In Region F, all (100%) of the trees were found in the “maintained open space” category.

Table 7.23: Percentage distribution of land use categories for Searsia lancea

Land use category for *Searsia lancea*	**Region A**	**Region C**	**Region D**	**Region F**
Commercial	_	27.0	_	_
Commercial and median	_	_	16.7	_
Formal residential	80.0	45.9	_	_
Formal residential and median	_	_	33.3	_
Formal residential and open space maintained	_	_	16.7	_
Industrial	_	4.9	_	_
Maintained open space	_	_	_	100.0
Park	20.0	11.5	33.3	_
Vacant land	_	10.7	_	_
Total percentage	100	100	100	100

Figure 7.13 displays the distribution of the *S. lancea* trees in the study (Region A (n = 25); Region B (n = 0); Region C (n = 122); Region D (n = 204) and Region F (n = 28)) and the land uses of the trees are indicated in different colours and listed in the legend of the figure. These trees are spread across four of the regions (A, C, D and F) in the study, with none of the species found in Region B. The trees seen in Region E in this figure were allocated to Region A in the study as the region boundaries were changed subsequent to the survey part of this study.

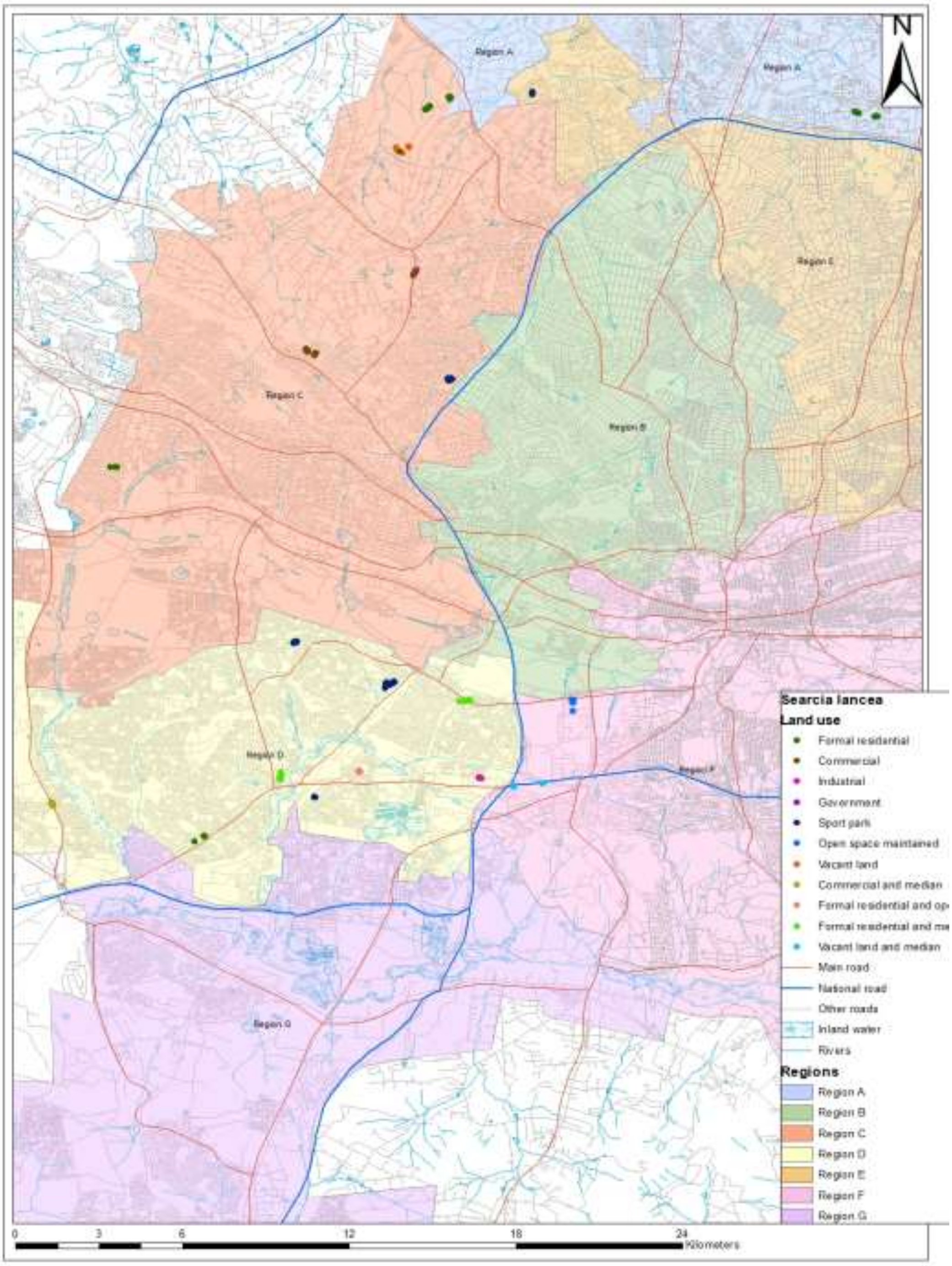


Figure 7.13: Land use of Searsia lancea *per region*

The results for the mean CGL and age of the *S. lancea* trees in the different land use categories for each region (Table 7.24) indicate that in Region C, the trees with the widest mean CGL (723 mm) were in the “park” land use category with a mean age of 15 years. The trees with the smallest mean CGL (319.45 mm) were in the “formal residential and open space-maintained” category in Region D with a mean age of 15 years. The oldest trees (16 years) were found in Region D in “commercial and median” (mean CGL of 626.15 mm) and “formal residential and open space maintained” (mean CGL of 319.45 mm) and in Region F in the “open space maintained” category (mean CGL of 596 mm). The youngest trees (12 years) were found in the “formal residential” category and had a mean CGL of 497.25 mm.

Table 7.24: Mean CGL and age per land use category for Searsia lancea

Region	**Land use category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region A	Formal residential	497.25	12	12
	Park	348.60	15	15
Region C	Commercial	571.27	14 and 15	15
	Formal residential	587.80	13 and 14	14
	Park	723.00	15	15
Region D	Commercial and median	626.15	16	16
	Formal residential and median	464.15	14 and 16	15
	Formal residential and open space	319.45	16	16
	Park	485.99	12 and 16	15
Region F	Open space maintained	596	16	16

7.4.2 The impact of land cover per species per region

Results for the distribution of land cover categories for each tree species are presented per region and thereafter for the mean circumference and the mean age of each tree species in the different regions.

7.4.2.1 Celtis africana

The results of the distribution of land cover categories for *C. africana* (Table 7.25) indicate that 100% of the trees in Region A were found in the “unmaintained grass” category and 100% in Region B were found in “maintained grass”. In Region C, 49.1% were found in “maintained grass”, followed by 19.2% in “bare soil and paving”, 17.8% in “bare soil” and 11.7% in “unmaintained grass”. In Region D, 65.4% were found in “maintained grass”, followed by 13.3% in “bare soil” and the remainder of the trees (20.4%) were found in small percentages in six land covers. In Region F, 100% of the trees were found in the “maintained grass” land cover.

Table 7.25: Percentage distribution of land cover categories for Celtis africana

Land cover category for *Celtis africana*	Region A	Region B	Region C	Region D	Region F
Bare soil	_	_	17.8	13.3	_
Bare soil and paving	_	_	19.2		_
Bare soil and hard landscaping	_	_	0.5	0.6	_
Hard landscaping	_	_	0.9	2.0	
Maintained grass	_	100	49.1	65.4	100
Maintained grass and plant bed	_	_	0.5	_	_
Maintained grass and paving	_	_	_	0.8	_
Plant bed	_	_	0.5	5.0	_
Paving	_	_		2.8	_
Paving and hard landscaping	_	_	_	1.2	_
Unmaintained grass	100	_	11.7	8.9	_
Total percentage	100	100	100	100	100

The results for the mean CGL and age of the *C. africana* trees in the different land cover categories for each region (Table 7.26) reveal that the trees with the widest mean CGL (873.62 mm) were in the “bare soil” land cover category in Region F with a mean age of 14 years. The trees with the smallest mean CGL (404.10 mm) were in the “unmaintained grass” category in Region A with a mean age of 12 years. The trees in Region F (12 years with a mean CGL of 404.10 mm) found in the “unmaintained grass” land use were the youngest trees in the study and the oldest trees (16 years) were found in Region D in the “bare soil” land use with a mean CGL of 587.75 mm.

Table 7.26: Mean CGL and age per land cover category for Celtis africana

Region	Land cover category	Mean CGL per category (mm)	Minimum and maximum ages (years)	Mean age (years)
Region A	Unmaintained grass	404.10	12	12
Region B	Maintained grass	436.66	15	15
Region C	Bare soil	457.73	12 and 15	14
	Bare soil and paving	391.39	13 and 15	14
	Maintained grass	557.27	13 and 15	14
Region D	Bare soil	578.75	16	16
	Maintained grass	595.39	13 and 15	14
Region F	Bare soil	873.62	14	14
	Maintained grass	485.63	14	14

7.4.2.2 *Combretum erythrophyllum*

The results of the distribution of land cover categories for *C. erythrophyllum* (Table 7.27) indicate that in Region A, 54.5% of the trees were found in “unmaintained grass” and 45.5% in “maintained grass” and in Region B, 100% were found in “maintained grass”. In Region C, 32.3% of the trees were found in the “unmaintained grass” land cover category, followed by 24.9% in “bare soil” and 20.4% in “maintained grass”. The remainder of the trees (20.5%) were found in small percentages in five categories. 75.7% of the *C. erythrophyllum* trees in Region D were found in “maintained grass”, followed by 12,3% in “bare soil”. The remainder of the trees (12%) were found in small percentages in three land covers. In Region F, 85% were found in “maintained grass” and 15% in “bare soil”.

Table 7.27: Percentage distribution of land cover categories for Combretum erythrophyllum

Land cover category for *Combretum erythrophyllum*	**Region A**	**Region B**	**Region C**	**Region D**	**Region F**
Bare soil	_	_	24.9	12.3	15.0
Bare soil and paving	_	_	_	3.6	_
Hard landscaping	_	_	_	0.3	_
Maintained grass	45.5	100	20.4	75.7	85.0
Maintained grass and paving	_	_	0.4	_	_
Paving	_	_	7.7	_	_
Paving and hard landscaping	_	_	5.3	_	_
Paving and irrigation	_	_	6.7	_	_
Paving and plant bed	_	_	_	_	_
Plant bed	_	_	_	2.1	_
Plant bed and irrigation	_	_	0.4	_	_
Unmaintained grass	54.5	_	32.3	_	_
Total percentage	100	100	100	100	100

The results for the mean CGL and age of the *C. erythrophyllum* trees in the different land cover categories for each region (Table 7.28) indicate that the trees with the widest mean CGL (823.50 mm) were found in the “bare soil” land cover category in Region F with a mean age of 14 years. The trees with the smallest mean CGL (229.83 mm) were found in the “unmaintained grass” category in Region A with a mean age of 12 years. The trees in Region A were also the youngest trees in the study and the trees in Region C (mean CGL of 427.16 mm) and Region D (mean CGL of 481.80 mm) were both found in the “maintained grass” category and were the oldest trees (16 years).

Table 7.28: Mean CGL and age per land cover category for Combretum erythrophyllum

Region	Land cover category	Mean CGL per category (mm)	Minimum and maximum ages (years)	Mean age (years)
Region A	Unmaintained grass	229.83	12	12
Region B	Maintained grass	310.14	13 and 15	14
Region C	Bare soil	444.88	14 and 16	15
	Maintained grass	427.16	13 and 12	15
	Unmaintained grass	309.03	13 and 15	14
Region D	Bare soil	368.73	15	15
	Maintained grass	481.80	13 and 16	15
Region F	Bare soil	823.50	14	14
	Maintained grass	527.23	13 and 14	13

7.4.2.3 Olea europaea subsp. *africana*

The results of the distribution of land cover categories for *O. europaea* subsp. *africana* are depicted in Table 7.29. None of these trees were found in Regions A and B. In Region C, 53.4% of the trees were found in “bare soil”, 17.4% in “unmaintained grass” and 13% each in “maintained grass” and “paving”. The remaining 3.1% of the trees were found in small percentages in three land covers. In Region D, 73.3% of the trees were found in “maintained grass” and 12.4% in “maintained grass and bare soil”. The remainder of the trees (12.6%) were found in three land cover categories.

Table 7.29: Percentage distribution of land cover categories for Olea europaea subsp. africana

Land cover category for *Olea europaea subsp. africana*	Region C	Region D	Region F
Bare soil	53.4	3.7	_
Maintained grass	13.0	73.3	100
Maintained grass and Soil	_	12.4	_
Paving	13.0	9.9	_
Paving and Hard landscaping	1.9	_	_
Paving and plant bed	0.6	_	_
Plant bed	0.6	_	_
Unmaintained grass	17.4	0.6	_
Total percentage	100	100	100

The results for the mean CGL and age of the *O. europaea* subsp. *africana* trees in the different land cover categories for each region (Table 7.30) show that the trees with the widest mean CGL (505.01 mm) were found in “paving” in Region C with a mean age of 14 years. The trees with the smallest mean CGL (275 mm) were in “maintained grass” with a mean age of 16 years in Region F. The youngest trees (13 years) were found in Region D in “paving” with a mean

CGL of 359.12 mm and the oldest trees (16 years) were found in Regions D and F in “maintained grass and bare soil” (mean CGL of 338.35 mm) and “maintained grass” (mean CGL of 275 mm), respectively.

Table 7.30: Mean CGL and age per land cover category for Olea europaea subsp. africana

Region	**Land cover category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region C	Bare soil	474.24	14 and 16	15
	Maintained grass	399.62	13 and 16	15
	Paving	505.01	13 and 14	14
	Unmaintained grass	437.96	13 and 16	15
Region D	Maintained grass	287.36	12 and 16	14
	Maintained grass and bare soil	338.35	16	16
	Paving	359.12	13	13
Region F	Maintained grass	275	16	16

7.4.2.4 Searsia lancea

The results of the distribution of land cover categories for S. *lancea* (Table 7.31) reveal that no *S. lancea* trees were found in Region B. In Region A, 80% of the trees were found in “unmaintained grass” and 20% in “maintained grass”. In Region C, 40.2% of the trees were found in “maintained grass“, followed by 20.5% in “bare soil”, 18% in “unmaintained grass”, 16.4% in “paving” and the remaining 4.9% of the trees were found in small percentages in two land covers. The *S. lancea* trees in Region D were found in “maintained grass” (35%), “unmaintained grass” (20.8%), “paving and plant bed” (16.7%), “plant bed and irrigation” (12.5%) and “hard landscaping” (11.7%). In Region F, 60% of the trees were found in the “plant bed” and 40% in the “maintained grass” categories.

Table 7.31: Percentage distribution of land cover categories for Searsia lancea

Land cover categories for *Searsia lancea*	**Region A**	**Region C**	**Region D**	**Region F**
Bare soil	_	20.5	_	_
Hard landscaping	_	1.6	11.7	_
Maintained grass	20.0	40.2	35.0	40.0
Paving	_	16.4	_	_
Paving and plant bed	_	_	16.7	_
Plant bed	_	3.3	3.3	60.0
Plant bed and irrigation	_	_	12.5	_
Unmaintained grass	80.0	18.0	20.8	_
Total percentage	100	100	100	100

The results for the mean CGL and age of the *S. lancea* trees in the different land cover categories for each region (Table 7.32) indicate that the trees with the widest mean CGL (697.15 mm) were found in the “paving” category in Region C with a mean age of 15 years. The trees with the smallest mean CGL (330.8 mm) were found in the “paving and plant bed” category in Region D with a mean age of 14 years. The youngest trees (12 years) were found in “unmaintained grass” (mean CGL of 497.25 mm) in Region A. The oldest trees (16 years) were found in Region D in “unmaintained grass” (mean CGL of 656.77 mm) and in Region F in “maintained grass” (mean CGL of 542 mm) and “plant bed” (mean CGL of 523.16 mm).

Table 7.32: Mean CGL and age per land cover category for Searsia lancea

Region	**Land cover category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region A	Maintained grass	348.00	15	15
	Unmaintained grass	497.25	12	12
Region C	Bare soil	549.68	13 and 14	14
	Maintained grass	613.61	14 and 15	14
	Paving	697.15	15	15
	Unmaintained grass	378.22	14 and 16	15
Region D	Hard landscaping	677.16	14	14
	Maintained grass	477.03	12 and 16	15
	Paving and plant bed	330.80	14	14
	Plant bed and irrigation	604.00	14	14
	Unmaintained grass	656.77	16	16
Region F	Maintained grass	542.00	16	16
	Plant bed	523.16	16	16

7.4.3 The impact of maintenance needs per species per region

The distribution of maintenance needs categories for each tree species is presented per region and thereafter for the mean circumference and mean ages of the trees in the different regions.

7.4.3.1 Celtis africana

The results of the distribution of maintenance needs categories for *C. africana* (Table 7.33) indicate that in Region A, 85% of the trees required no maintenance and the remaining 15% were equally distributed between "pruning" and "wires or cable ties around stems". In Region B, 78.2% of the trees needed pruning and 21.8% did not require maintenance. In Region C, 69.3% did not require maintenance, 17.5% required pruning and the remaining 14.2% fell into the "pruning and skew growth form" category. In Region D, 52.8% of the trees did not need maintenance and 12.2% needed pruning. The remaining 16.6% needed pruning of coppice growth, had wires or cable ties around stems or were skew and the remaining 19.4% fell into a number of categories related to pruning. In Region F, 48.1% of the trees needed no maintenance, 40.7% needed structural pruning and the remaining 8.5% fell into the "skew growth form" category.

Table 7.33: Percentage distribution of maintenance needs for Celtis africana

Maintenance needs categories for *Celtis africana*	**Region A**	**Region B**	**Region C**	**Region D**	**Region F**
Coppice and pruning	_	_	3.8	7.7	7.4
Coppice, pruning and bark damage	_	_	1.4		_
Coppice, pruning and wires or cable ties	_	_	_	0.2	_
Coppice, dead branches and pruning	_	_	0.9	1.8	_
Coppice, dead branches, pruning and wires or cable ties	_	_	_	6.9	_
No maintenance required	85.0	21.8	69.3	52.8	48.1
Pruning and bark damage	_	_	1.4	0.2	_
Pruning and dead branches	_	_	3.2	7.1	_
Pruning and skew growth form	_	_	0.9	_	_
Pruning (structural)	5.0	78.2	17.5	12.2	40.7
Pruning and wires or cable ties	5.0	_	_	3.0	_
Skew growth form of trees	_	_	_	0.4	3.7
Wires or cable ties around stems	5.0	_	1.4	7.5	_
Total percentage	100	100	100	100	100

The results for the mean CGL and age of the *C. africana* trees in the different maintenance needs categories for each region (Table 7.34) indicate that the trees with the widest mean CGL (649.55 mm) were found in Region D in the "combination of different pruning requirements" category and had a mean age of 14 years. The trees with the smallest mean CGL (445.75 mm) were found in Region A, needed no maintenance and had a mean age of

12 years. The trees in Region A were also the youngest trees in the study. The oldest trees were found in Region D at 16 years old with a mean CGL of 560.85 mm and did not need maintenance, those with a mean CGL of 614.17 mm needed structural pruning and those with a mean CGL of 649.55 mm fell into the “pruning combination” category.

Table 7.34: Mean CGL and age per maintenance needs category for Celtis africana

Region	Maintenance needs category	Mean CGL per category (mm)	Minimum and maximum ages (years)	Mean age (years)
Region A	None	445.75	12	12
Region B	Pruning combination	480	15	51
Region C	None	539.48	12 and 15	14
	Pruning (structural)	447.22	13 and 15	14
	Pruning combination	509.84	13 and 15	14
Region D	None	560.85	13 and 16	14
	Pruning (structural)	614.17	14 and 15	16
	Pruning combination	649.55	14 and 16	16
Region F	None	605.34	14	14
	Pruning (structural)	513.70	14	14

7.4.3.2 Combretum erythrophyllum

The results of the distribution of maintenance needs categories for *C. erythrophyllum* (Table 7.35) indicate that in Region A, 63.6% of the trees did not need maintenance, 22% fell into the “coppice and pruning” category and the remaining 13.6% needed structural pruning. In Region B, 86.3% of the trees did not need maintenance and the remaining 13.4% needed structural pruning. In Region C, 29.1% did not need maintenance, but 32.7% needed pruning of coppice growth and 16% structural pruning. The remaining 23.2% were found in four categories in small percentages. In Region D, 44% needed no maintenance, 32.8% needed pruning of coppice growth and 13.9% structural pruning. In Region F, 47.5% were found in the category “coppice and pruning”, 45% did not need any maintenance and the remaining 7.5% were divided into three categories.

Table 7.35: Percentage distribution of maintenance needs for Combretum erythrophyllum

Maintenance needs for *Combretum erythrophyllum*	**Region A**	**Region B**	**Region C**	**Region D**	**Region F**
Bark damage	_	_	0.7	0.3	_
Coppice, dead branches and pruning	_	_	4.3	_	2.5
Coppice, dead branches, pruning and wires	_	_	6.8	0.9	_
Coppice and pruning	22.7		32.7	32.8	47.5
Coppice, pruning and bark damage	_	_	0.7	3.6	2.5
Coppice, pruning and skew growth	_	_	1.8	0.3	_
Coppice, pruning and wires or cable ties	_	_	1.4	_	_
Dead branches and pruning	_	_	2.8	1.2	_
No maintenance required	63.6	86.3	29.1	44.0	45.0
Pruning and bark damage	_	_	0.4	_	_
Pruning and skew growth form	_	_	1.8	0.9	_
Pruning (structural)	13.6	13.4	16.0	13.9	2.5
Pruning and wires or cable ties	_	_		0.3	_
Skew	_	_	0.7	1.2	_
Wires or cable ties around stems	_	_	3.2	0.6	_
Total percentage	100	100	100	100	100

The results for the mean CGL and age of the *C. erythrophyllum* trees in the different maintenance needs categories for each region (Table 7.36) indicate that the trees with the widest mean CGL (775.89 mm) did not require maintenance and were found in Region F with a mean age of 13 years. The trees with the smallest mean CGL (181.78 mm) were found in Region A, did not require maintenance and had a mean age of 12 years. The trees in Region A were the youngest (12 years), found in the “coppice and pruning” category with a mean CGL of 288.25 mm, in the “no maintenance required” category with a mean CGL of 181.78 mm and in the “structural pruning” category with a mean CGL of 275.66 mm. The oldest trees (16 years) did not need maintenance and had a mean CGL of 614.29 mm.

Table 7.36: Mean CGL and age per maintenance needs category for Combretum erythrophyllum

Region	Maintenance needs category	Mean CGL per category (mm)	Minimum and maximum ages (years)	Mean age (years)
Region A	Coppice and pruning	288.25	12	12
	No maintenance required	181.78	12	12
	Pruning (structural)	275.66	12	12
Region B	No maintenance required	235.70	13	13
	Pruning (structural)	382.51	14 and 15	14
Region C	Coppice and pruning	388.38	13 and 16	14
	No maintenance required	614.29	13 and 16	14
	Pruning (structural)	320.10	13 and 16	14
	Pruning combination	348.64	13 and 16	14
Region D	Coppice and pruning	443.88	10 and 16	15
	No maintenance required	492.06	13 and 16	15
	Pruning (structural)	385.02	15	15
	Pruning combination	555.53	10 and 16	15
Region F	Coppice and pruning	318.35	10	10
	No maintenance required	775.89	13	13

7.4.3.3 Olea europaea subsp. *africana*

No *O. europaea* subsp. *africana* trees were found in Regions A and B. Table 7.37 indicates that in Region C, 25.5% of the trees did not need maintenance, 29.4% needed pruning of coppice growth and 19.6% needed structural pruning. The remaining 24.9% were divided into eight categories such as “skew growing trees”, “bark damage” and different categories of pruning. In Region D, 39.6% of the trees did not need maintenance, 23.9% needed structural pruning and 22% needed pruning of coppice growth. The remaining 14.5% of the trees were divided into categories such as “skew trees”, “wires or cable ties around stems”, “bark damage” and different forms of corrective pruning. In Region F, 90% of the trees did not require maintenance and the remaining 10% were equally divided between “structural pruning” and “skew growing trees”.

Table 7.37: Percentage distribution of maintenance needs for Olea europaea subsp. africana

Maintenance needs categories for *Olea europaea subsp. africana*	**Region C**	**Region D**	**Region F**
Bark damage	1.3	1.3	_
Coppice, dead branches and pruning	11.8	_	_
Coppice and pruning	29.4	22.0	_
Coppice, pruning and skew growth	3.9	1.9	_
Coppice, pruning and wires or cable ties	1.3	1.9	_
Dead branches and pruning	1.3	3.1	_
No maintenance required	25.5	39.6	90.0
Pruning (structural)	19.6	23.9	5.0
Pruning and bark damage	0.7	_	_
Pruning and skew growth form	_	1.9	_
Pruning and wires or cable ties	1.3	_	_
Skew	3.3	2.5	5.0
Wires or cable ties around stems	_	1.9	_
Total percentage	100	100	100

The results for the mean CGL and age of the *O. europaea* subsp*. africana* trees in the different maintenance needs categories for each region (Table 7.38) reveal that the trees with the widest mean CGL (485.82 mm) required structural pruning, were in Region C and had a mean age of 14 years. The trees with the smallest mean CGL (257.93 mm) in Region D were found in the “pruning combination” category with a mean age of 15 years. The *O. europaea* subsp. *africana* trees with the minimum mean age (12 years) were found in Region C in the “coppice and pruning” category with a mean CGL of 461.26 mm. The trees with the maximum mean age (16 years) did not need any maintenance and had a mean CGL of 480.24 mm in Region C, needed structural pruning and had a mean CGL of 288.17 mm in Region D and needed no maintenance and had a mean CGL of 275 mm in Region F.

Table 7.38: Mean CGL and age per maintenance needs category for Olea europaea subsp. africana

Region	**Maintenance needs category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region C	Coppice and pruning	461.26	12 and 13	12
	Dead branches, coppice and pruning	440.78	14 and 16	15
	No maintenance required	480.24	13 and 16	16
	Pruning (structural)	485.82	13 and 15	14
Region D	Coppice and pruning	309.45	14 and 16	15
	No maintenance required	315.36	12 and 16	14
	Pruning (structural)	288.17	16	16
	Pruning combination	257.93	14 and 16	15
Region F	No maintenance required	275	16	16

7.4.3.4 Searsia lancea

The results of the distribution of maintenance needs categories for *S. lancea* (Table 7.39) show that in Region A, 80% of the trees did not need maintenance, 12% had dead branches and needed pruning and 8% fell into the “coppice and pruning” category. No *S. lancea* trees were found in Region B. In Region C, 51.1% did not require maintenance, 25.6% fell into the “coppice and pruning” category, 14% needed structural pruning and the remaining 7.4% of the trees fell into six maintenance categories in small percentages. In Region D, 50% of the trees did not need maintenance, 14.2% needed structural pruning and 13.1% fell into 10 categories. In Region F, 95% of the trees needed no maintenance and 5% fell into the “coppice, pruning and bark damage” category.

Table 7.39: Percentage distribution of maintenance needs for Searsia lancea

Maintenance needs categories for *Searsia lancea*	**Region A**	**Region C**	**Region D**	**Region F**
Coppice and pruning	8.0	25.6	0.8	_
Coppice, pruning and bark damage	_	_	2.5	5.0
Coppice, pruning and skew growth	_	0.8	0.8	_
Coppice, pruning and wires or cable ties	_	2.5	0.8	_
Dead branches, coppice and pruning	_	1.7	_	_
Dead branches and pruning	12.0	0.8	2.5	_
No maintenance required	80.0	52.1	50	95.0
Pruning (structural)	_	14.0	14.2	_
Pruning and bark damage	_	_	0.8	_
Pruning and skew growth form	_	_	0.8	_
Pruning and wires or cable ties	_	_	0.8	_
Skew	_	0.8	2.5	_
Wires or cable ties around stems	_	0.8	0.8	_
Total percentage	100	100	100	100

The results for the mean CGL and age of the *S. lancea* trees in the different maintenance needs categories for each region (Table 7.40) show that the trees with the widest mean CGL (614.39 mm) did not need maintenance, had a mean age of 14 years and were in Region C. The trees with the smallest mean CGL (224.79 mm) also did not need any maintenance, had a mean age of 14 years and were in Region D. Trees that had a mean age of 12 years and did not need maintenance were in Region A and the oldest trees (16 years) were found in the “pruning combination” category (mean CGL of 538.35 mm) in Region D and those that needed no maintenance (mean CGL of 596 mm) were in Region F.

Table 7.40: Mean CGL and age per maintenance needs category for Searsia lancea

Region	**Maintenance needs category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region A	No maintenance required	497.25	12	12
	Pruning combined	348.60	15	15
Region C	No maintenance required	614.39	14 and 15	14
	Pruning (structural)	542.11	13 and 15	14
	Pruning combination	525.33	13 and 15	14
Region D	No maintenance required	224.79	12 and 16	14
	Pruning (structural)	346.00	12 and 16	14
	Pruning combination	538.35	16	16
Region F	No maintenance required	596.00	16	16

7.4.4 The impact of pests and diseases per species per region

The distribution of the categories of pests and diseases for each tree species is presented per region and thereafter for the mean circumference of each tree species in the different regions, with the aim to determine if pests and diseases in a specific region had an impact on the growth of the trees.

7.4.4.1 Celtis africana

The results of the distribution of the presence of pests and diseases on *C. africana* (Table 7.41) show that in Region B no pests were found on these trees. In Region A insects were found on all (100%) of the trees. In Region C, 77.1% of the trees had no pests and diseases, 21.55% had insects and 1.4% had diseases. In Region D, 94% of the trees did not have any pests and diseases but insects were found on the remaining 6%. In Region F, 48.7% of the trees did not have any pests and diseases but insects and diseases were found on 41% of the trees. There were also trees with just diseases (7.7%) and just insects (2.6%) in Region F. No viruses were visible on any of the *C. africana* trees.

Table 7.41: Percentage distribution of pests and diseases for Celtis africana

Pest and disease categories for *Celtis africana*	**Region A**	**Region B**	**Region C**	**Region D**	**Region F**
Diseases	_	_	1.4	_	7.7
Insects	100.0	_	21.5	6.0	2.6
Insects and diseases	_	_	_	_	41.0
No pests and diseases	_	100.0	77.1	94.0	48.7
Viruses	_	_	_	_	_
Total percentage	100	100	100	100	100

The results for the mean CGL and age of the *C. africana* trees with pests and diseases for each region (Table 7.42) indicate that the trees with the widest mean CGL (744.08 mm) were 14 years old, did not have any pests and diseases and were found in Region F. The trees with the smallest mean CGL (380.23 mm) were also found in Region F, had insects and diseases and were also 14 years old. The youngest trees (12 years) were found in Region C, had insects and a mean CGL of 486.47 mm and the oldest trees (16 years) were found in Region D and did not have any pests and diseases.

Table 7.42: Mean CGL and age per pest and disease category for Celtis africana

Region	Pest and disease category	Mean CGL per category (mm)	Minimum and maximum ages (years)	Mean age (years)
Region A	Insects	425.39	15	15
Region B	No pests and diseases	480.00	15	15
Region C	Insects	486.47	8 to 15	9
	No pests and diseases	526.62	13 to 15	14
Region D	No pests and diseases	597.91	13 to 16	16
Region F	Insects and diseases	380.23	14	14
	No pests and diseases	744.08	14	14

7.4.4.2 Combretum erythrophyllum

The results of the distribution of the presence of pests and diseases on *C. erythrophyllum* (Table 7.43) reveal that none of the trees in Regions A and F had any pests and diseases and neither did most of the trees in Region B (97.2%), Region C (94.4%) and Region D (94.9%). Insects were found on the rest of the trees in Region B (2.8%), Region C (5.6%) and Region D (5.1%). No viruses or diseases were visible on any of the *C. erythrophyllum* trees in any of the regions.

Table 7.43: Percentage distribution of pests and diseases for Combretum erythrophyllum

Pest and disease categories for ***Combretum erythrophyllum***	Region A	Region B	Region C	Region D	Region F
Insects	_	2.8	5.6	5.1	_
No pests and diseases	100	97.2	94.4	94.9	100
Total percentage	100	100	100	100	100

The results for the mean CGL and ages of the *C. erythrophyllum* trees with pests and diseases for each region (Table 7.44) show that the trees with the smallest CGL (229 mm) were found in Region A with a mean age of 13 years and had no pests and diseases. The trees with the widest mean CGL (558 mm) were found in Region F with a mean age of 14 years and had no pests and diseases.

Table 7.44: Mean CGL and age per pest and disease category for Combretum erythrophyllum

Region	Pest and disease category	Mean CGL per category (mm)	Minimum and maximum ages (years)	Mean age (years)
Region A	No pests and diseases	229	12 and 15	13
Region B	No pests and diseases	310	13 and 15	14
Region C	No pests and diseases	447	13 and 16	15
Region D	No pests and diseases	379	14 and 16	15
Region F	No pests and diseases	558	13 and 14	14

7.4.4.3 Olea europaea subsp. *africana*

The results of the distribution of the presence of pests and diseases of *O. europaea* subsp. *africana* (Table 7.45) show that none of this species was found in Regions A and B and none of the trees in Region F had any pests and diseases. In Region C, 40.5% of the trees had no pests and diseases, 31.9% did have insects and diseases and the remaining 14.7% had insects. In Region D, 56.7% had no pests and diseases, 17.2% had viruses and 10.8% had insects, diseases and viruses. The remaining 15.3% were found across three categories.

Table 7.45: Percentage distribution of pests and diseases for Olea europaea subsp. africana

Pest and disease categories for ***Olea europaea subsp. africana***	Region A	Region B	Region C	Region D	Region F
Insects	_	_	14.7	3.8	_
Insects and diseases	_	_	31.9	3.2	_
Insects, diseases and viruses	_	_	_	10.8	_
Insects and viruses	_	_	_	8.3	_
No pests and diseases	_	_	40.5	56.7	100.0
Viruses	_	_	12.9	17.2	_
Total percentage	100	100	100	100	100

The results for the mean CGL and age of the *O. europaea* subsp. *africana* trees with pests and diseases (Table 7.46) indicate that the trees with the widest mean CGL (522.49 mm) did not have any pests and diseases, had a mean age of 14 years and were in Region C. The trees with the smallest mean CGL (275 mm) were found in Region F, had no pests and diseases and were also the trees with the maximum ages (16 years). The trees with the minimum mean age (12 years) did not have any pests and diseases and were in Region D.

Table 7.46: Mean CGL and age per pest and disease category for Olea europaea subsp. africana

Region	Pest and disease category	Mean CGL per region	Minimum and maximum ages (years)	Mean ages (years)
Region C	Insects and diseases	430.56	14	14
	Insects	263.29	13 and 16	14
	No pests and diseases	522.49	13 and 16	14
	Viruses	372.13	14 and 15	14
Region D	Insects and viruses	274.92	15	15
	No pests and diseases	314.36	12 and 16	15
	Viruses	266.81	15	15
Region F	No pests and diseases	275.00	16	16

7.4.4.4 Searsia lancea

The results of the distribution of the presence of pests and diseases on *S. lancea* (Table 7.47) indicate that none of the trees in Region B had any pests and diseases and neither did 96% of the trees in Region A. 4% of the trees in Region A had insects. In Region C, 97.5% of the trees had no pests and diseases and 2.5% had insects. In Region D, 83.3% of the trees had no pests and diseases and 16.7% had insects. In Region F, none of the trees had pests and diseases. No diseases, viruses or combinations thereof were found on any of the *S. lancea* trees in any of the regions.

Table 7.47: Percentage distribution of pests and diseases for Searsia lancea

Pest and disease categories for ***Searsia lancea***	Region A	Region B	Region C	Region D	Region F
Insects	4.0	_	2.5	16.7	_
No pests and diseases	96.0	_	97.5	83.3	100.0
Total percentage	100	100	100	100	100

The results for the mean CGL and age of the *S. lancea* trees with pests and diseases for each region (Table 7.48) show that the trees with the widest mean CGL (657.42 mm) had no pests and diseases, were in Region D and had a mean age of 14 years. The trees with the smallest mean CGL (467 mm) were found in Region A with no pests and diseases and had a mean age of 12 years. These trees were also the youngest trees in the study. The oldest trees (16 years) were found in Region F with no pests and diseases.

Table 7.48: Mean CGL and age per pest and disease category for Searsia lancea

Region	**Pest and disease category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region A	No pests and diseases	467.00	12	12
Region C	No pests and diseases	574.00	13 and 15	14
Region D	Insects	657.42	13 and 16	14
	No pests and diseases	480.48	12 and 16	15
Region F	No pests and diseases	596.00	16	16

7.4.5 The impact of human influence per species per region

The distribution of human influence categories for each tree species is presented per region and thereafter for the mean circumference of each tree species in the different regions, with the aim to determine if human influence in a specific region has an impact on the growth of the trees.

7.4.5.1 Celtis africana

The results of the distribution of the human influence categories for *C. africana* (Table 7.49) indicate that in Region F, 77.5% of the trees were found in “maintained lawn”, 16.3% in “unmaintained lawn” and the remaining 6.3% in “unmaintained lawn” with rubble surrounding the tree stem. In Region D, 44.7% of the trees were found in “maintained lawn”, 19.3% close to pedestrian traffic and 14.1% were in the “pedestrian traffic in maintained lawn” category. The remaining 22.9% of the trees were spread over five human influence categories in small percentages. In Region C, 41.6% of the trees were found in “maintained lawn” and 40.7% in “unmaintained lawn”. The remaining 18.7% of the *C. africana* trees were spread over six human influence categories.

Table 7.49: Percentage distribution of human influence on Celtis africana

Human influence categories for *Celtis africana*	**Region A**	**Region B**	**Region C**	**Region D**	**Region F**
Bark harvesting	_	_	2.8	_	_
Informal trading	_	_	1.4	0.8	_
Maintained lawn		100	41.6	44.7	77.5
Pedestrian traffic and maintained lawn	_	_	_	14.1	_
Pedestrian traffic	_	_	0.5	19.3	_
Rubble surrounding the tree stem	_	_	1.8	1.6	_
Rubble and lawn not maintained	_	_	2.3	8.9	6.3
Unmaintained lawn	100		40.7	8.9	16.3
Vehicles present	_	_	8.8	1.8	_
Total percentage	100	100	100	100	100

The results for the mean CGL and age of the *C. africana* trees in the human influence categories for each region (Table 7.50) show that the trees with the widest mean CGL (926.83 mm) were 14 years old and found in "unmaintained lawn" in Region F. The trees with the smallest mean CGL (425.39 mm) were found in Region A in "unmaintained lawn" and were 12 years old. The trees in Region F were the youngest and the trees in Region D found in the "pedestrian traffic and maintained lawn" category with a mean CGL of 681.89 mm were 16 years old.

Table 7.50: Mean CGL and age per human influence category for Celtis africana

Region	**Human influence category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region A	Unmaintained lawn	425.39	12	12
Region B	Maintained lawn	480.00	15	15
Region C	Maintained lawn	644.93	12 and 15	14
	Unmaintained lawn	440.06	12 and 14	13
Region D	Maintained lawn	550.85	14 - 16	16
	Pedestrian traffic	661.68	13 - 16	16
	Pedestrian traffic and maintained lawn	681.89	16	16
Region F	Maintained lawn	465.92	14	14
	Unmaintained lawn	926.83	14	14

7.4.5.2 Combretum erythrophyllum

The results of the distribution of the human influence categories for *C. erythrophyllum* (Table 7.51) show that in Region A, 45.5% of the trees were found in "maintained lawn" and 54.5%

in “unmaintained lawn”. In Region B, all the trees were found in “maintained lawn”. In Region C, 48.6% of the trees were found in “unmaintained lawn” and 22.9% in “maintained lawn”. The remaining 28.4% of the *C. erythrophyllum* trees were found in six different human influence categories. In Region D, 75.1% of the trees were found in “maintained lawn” and the remaining 24.9% were spread over five human influence categories in small percentages. In Region F, 52.5% of the trees were found in “maintained lawn” and 45% in “unmaintained lawn”.

Table 7.51: Percentage distribution of human influence on Combretum erythrophyllum

Human influence categories for *Combretum erythrophyllum*	**Region A**	**Region B**	**Region C**	**Region D**	**Region F**
Bark harvesting and maintained lawn	_	_	8.4	7.2	_
Informal trading and bark harvesting	_	_	0.7	_	_
Maintained lawn	45.5	100	22.9	75.1	52.5
Pedestrian traffic	_	_	7.7		_
Pedestrian traffic and maintained lawn	_	_	3.5	3.9	_
Pedestrian traffic and unmaintained lawn	_	_	0.7	6.0	_
Rubble	_	_	_	1.8	2.5
Unmaintained lawn	54.5	_	48.6	6.0	45.0
Vehicles present	_	_	7.4	_	_
Total percentage	100	100	100	100	100

The results for the mean CGL and age of the *C. erythrophyllum* trees in the human influence categories for each region (Table 7.52) reveal that the trees with the widest mean CGL (791.05 mm) were found in “unmaintained lawn” in Region F with a mean age of 14 years. The trees with the smallest mean CGL (227.85 mm) were found in Region A in the “maintained lawn” category with a mean age of 14 years. The youngest trees (12 years) were found in Region A in “maintained lawn” with a mean CGL of 227.85 mm and in “unmaintained lawn” with a mean CGL of 229.83 mm. The oldest trees (16 years) were found in Region C with a mean CGL measurement of 508.20 mm in “maintained lawn”.

Table 7.52: Mean CGL and age per human influence category for Combretum erythrophyllum

Region	**Human influence category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region A	Maintained lawn	227.85	12 and 15	13
	Unmaintained lawn	229.83	8	12
Region B	Maintained lawn	310.00	13 and 15	14
Region C	Maintained lawn	508.20	13 and 16	15
	Unmaintained lawn	402.45	13 and 15	14
Region D	Maintained lawn	470.92	13 and 15	14
Region F	Maintained lawn	365.85	13	13
	Unmaintained lawn	791.05	14	14

7.4.5.3 Olea europaea subsp. *africana*

The results of the distribution of the human influence categories for *O. europaea* subsp. *africana* (Table 7.53) indicate that none of the trees were found in Regions A and B. In Region C, 21.1% of the trees were found in “maintained lawn”, 20.5% in “pedestrian traffic in unmaintained lawn”, 13.6% in “rubble surrounding the tree stem”, 13% in “unmaintained lawn” and 12.4% in “pedestrian traffic”. The remaining 19.4% of these trees were found in four human influence categories in small percentages. In Region D, 72% of the trees were found in “maintained lawn” and the remaining 28% in “pedestrian traffic and maintained lawn”. All the trees (100%) in Region F were found in “maintained lawn”.

Table 7.53: Percentage distribution of human influence on Olea europaea subsp. africana

Human influence categories for *Olea europaea* subsp. *africana*	**Region C**	**Region D**	**Region F**
Bark harvesting and maintained lawn	0.6	_	_
Informal trading, bark harvesting and lawn not maintained	9.9	_	_
Maintained lawn	21.1	72.0	100.0
Pedestrian traffic	12.4	_	_
Pedestrian traffic and maintained lawn	3.1	28.0	_
Pedestrian traffic and unmaintained lawn	20.5	_	_
Rubble surrounding the tree stem	13.6	_	_
Unmaintained lawn	13.0	_	_
Vehicles present	5.6	_	_
Total percentage	100	100	100

The results for the mean CGL and age of the *O. europaea subsp. africana* trees in the human influence categories for each region (Table 7.54) show that the trees with the widest mean

CGL (531.65 mm) were found in the “pedestrian traffic” category in Region C with a mean age of 14 years. The trees with the smallest mean CGL (217.26 mm) were found in Region F in “maintained lawn” with a mean age of 16 years. The youngest trees (13 years) were found in Region D in “pedestrian traffic and maintained lawn” with a mean CGL of 275 mm. The oldest trees (16 years) were found in Region D in “maintained lawn” with a mean CGL of 327.51 mm.

Table 7.54: Mean CGL and age per human influence category for Olea europaea subsp. africana

Region	**Human influence category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region C	Maintained lawn	474.24	13 and 16	15
	Pedestrian traffic	531.65	14	14
	Pedestrian traffic and lawn not maintained	454.51	14 and 16	15
	Rubble surrounding the tree stem	523.80	14	14
	Unmaintained lawn	423.09	13 and 16	14
Region D	Maintained lawn	327.51	13 and 16	16
	Pedestrian traffic and maintained lawn	217.26	13	13
Region F	Maintained lawn	275	16	16

7.4.5.4 Searsia lancea

The results of the distribution of the human influence categories for *S. lancea* (Table 7.55) indicate that none of the species were found in Region B. In Region A, 80% of the trees were found in “unmaintained lawn” and 20% in “maintained lawn”. In Region C, 55.7% of the trees were found in “maintained lawn”, 16.4% in “pedestrian traffic”, 13.9% in “unmaintained lawn” and 10.7% in “unmaintained lawn and vehicles”. The remaining 2.4% of the *S. lancea* trees were found in two human influence categories. In Region D, 60.8% of the trees were found in “maintained lawn”, 33.3% in “maintained lawn and pedestrian traffic” and the remaining 5.9% in two human influence categories in small percentages. All (100%) of the trees in Region F were found in “rubble surrounding the tree stem”.

Table 7.55: Percentage distribution of human influence on Searsia lancea

Human influence categories for *Searsia lancea*	**Region A**	**Region C**	**Region D**	**Region F**
Bark harvesting	_	1.6	1.7	_
Maintained lawn	20.0	55.7	60.8	_
Pedestrian traffic	_	16.4	_	_
Pedestrian traffic and maintained lawn	_	_	33.3	_
Pedestrian traffic and unmaintained lawn	_	_	4.2	_
Rubble surrounding the tree stem	_	0.8	_	100.0
Unmaintained lawn	80.0	13.9	_	_
Vehicles and lawn not maintained	_	10.7	_	_
Total percentage	100	100	100	100

The results for the mean CGL and age of the *S. lancea* trees in the human influence categories for each region are presented in Table 7.56. The trees with the widest mean CGL (697.15 mm) were found in the "pedestrian traffic" category in Region C with a mean age of 15 years. The trees with the smallest mean CGL (322.51 mm) were found in Region D in "maintained lawn with pedestrian traffic" and a mean age of 16 years. The lowest minimum age was 12 years, found in Region A in "unmaintained lawn" with a mean CGL of 497.25 mm. The oldest trees (16 years) were found in Region D in "maintained lawn" (mean CGL of 539.53 mm) and "pedestrian traffic and maintained lawn" (mean CGL of 322.51 mm) and in Region F in "rubble and maintained lawn" (mean CGL of 596 mm).

Table 7.56: Mean CGL and age per human influence category for Searsia lancea

Region	**Human influence category**	**Mean CGL per category (mm)**	**Minimum and maximum ages (years)**	**Mean age (years)**
Region A	Maintained lawn	348.6	15	15
	Unmaintained lawn	497.25	12	12
Region C	Maintained lawn	611.00	13 and 15	14
	Pedestrian traffic	697.15	15	15
	Unmaintained lawn	404.82	14 and 15	14
	Vehicles and lawn not maintained	427.07	13 and 15	14
Region D	Maintained lawn	539.53	16	16
	Pedestrian traffic and maintained lawn	322.51	16	16
Region F	Rubble and maintained lawn	596	16	16

7.4.6 The impact of conflict per tree species per region

The distribution of conflict categories for each tree species is presented per region and thereafter for the mean circumference of each tree species in the different regions, with the aim to determine if conflict in a specific region has an impact on the growth of the trees.

7.4.6.1 Celtis africana

The results of the distribution of the conflict categories for *C. africana* (Table 7.57) indicate that no conflict was found in Regions A, B and F. In Region C, 81.3% of the trees were found in the "no conflict" category, 12.6% in the "overhead structures" category and 6.1% in the "roads" category. In Region D, 79.4% of the trees were found with "no conflict", 10.1% were found in the "road" category and the remaining 10.4% in four conflict categories in small percentages.

Table 7.57: Percentage distribution of conflict for Celtis africana

Conflict categories for *Celtis africana*	**Region A**	**Region B**	**Region C**	**Region D**	**Region F**
Kerb and paving	_	_	_	0.2	_
No conflict	100	100	81.3	79.4	100
Overhead structures	_	_	12.6	0.8	_
Paving	_	_	_	4.8	_
Road	_	_	6.1	10.1	_
Sidewalk	_	_	_	4.6	_
Total percentage	100	100	100	100	100

The results for the mean CGL and age of the *C. africana* trees in the conflict categories for each region (Table 7.58) reveal that the trees with the widest mean CGL (657.32 mm) were found in the "overhead structures" category, were 14 years old and were in Region C. The trees with the smallest mean CGL (425.39 mm) were found in the "no conflict" category in Region A and were 12 years old. These trees in Region A were also the youngest trees. The oldest trees were 15 years old and found in Region B in the "no conflict" category with a mean CGL of 480 mm, and in Region D in the "no conflict" category with a mean CGL of 590.41 mm and in the "road" category with a mean CGL of 616 mm.

Table 7.58: Mean CGL and age per conflict category for Celtis africana

Region	Conflict category	Mean CGL per category (mm)	Minimum and maximum ages (years)	Mean age (years)
Region A	No conflict	425.39	12	12
Region B	No conflict	480.00	15	15
Region C	No conflict	487.87	12 and 15	14
	Overhead structures	657.32	14	14
Region D	No conflict	590.41	13 and 16	15
	Road	616.00	13 and 16	15
Region F	No conflict	557.39	14	14

7.4.6.2 Combretum erythrophyllum

The results of the distribution of the conflict categories for *C. erythrophyllum* (Table 7.59) show that no conflict was found in Regions A, B and F. In Region C, 72.5% of the trees were not in any conflict, 15.5% were found in the "overhead structures", 6.3% in the "road" and 5.6% in the "paving" categories. In Region D, no conflict was found with 99.7% of the trees and the remaining 0.3% of the trees were found in the "paving" category.

Table 7.59: Percentage distribution of conflict for Combretum erythrophyllum

Conflict categories for ***Combretum erythrophyllum***	Region A	Region B	Region C	Region D	Region F
No conflict	100	100	72.5	99.7	100.0
Overhead structures	_	_	15.5	_	_
Paving	_	_	6.3	0.3	_
Road	_	_	5.6	_	_
Total percentage	100	100	100	100	100

The results for the mean CGL and age of the *C. erythrophyllum* trees in the conflict categories (Table 7.60) reveal that the trees with the widest mean CGL (750.95 mm) were found in Region C in the "overhead structures" category with a mean age of 14 years. The trees with the smallest mean CGL (229 mm) were found in Region A in the "no conflict" category with a mean age of 13 years. These were also the youngest trees (12 years) in the study. The oldest trees (16 years) were found in Region D with a mean CGL of 379 mm in the "no conflict" category.

Table 7.60: Mean CGL and age per conflict category for Combretum erythrophyllum

Region	Conflict category	Mean CGL per category (mm)	Minimum and maximum ages (years)	Mean age (years)
Region A	No conflict	229.00	12 and 15	13
Region B	No conflict	310.00	13 and 15	14
Region C	No conflict	447.00	13 and 15	14
	Overhead structures	750.95	13 and 16	14
Region D	No conflict	379.00	13 and 16	15
Region F	No conflict	558.00	13 and 14	14

7.4.6.3 *Olea europaea* subsp. *africana*

The results of the distribution of the conflict categories for *O. europaea* subsp. *africana* (Table 7.61) indicate that none of the trees were found in Regions A and B. In Region C, 73.9% of the trees were found in the "no conflict" category, 10% in the "road" category, 8.7% in "paving" and 6.8% in "overhead structures". The trees in Regions D and F were found in the "no conflict" category.

Table 7.61: Percentage distribution of conflict for Olea europaea subsp. africana

Conflict categories for *Olea europaea* subsp. *africana*	Region C	Region D	Region F
Kerb	0.6	_	_
No conflict	73.9	100	100
Overhead structures	6.8	_	_
Paving	8.7	_	_
Road	10.0	_	_
Total percentage	100	100	100

The results for the mean CGL and age of the *O. europaea* subsp. *africana* trees in the conflict categories (Table 7.62) indicate that the trees with the widest mean CGL (479 mm) were found in Region C in the "road" category with a mean age of 14 years. The trees with the smallest mean CGL (275 mm) were found in the "no conflict" category in Region F with a mean age of 16 years. The oldest trees were in Region F (16 years) and the youngest trees (14 years) were in Region C in the "road" category.

Table 7.62: Mean CGL and age per conflict category for Olea europaea subsp. africana

Region	Conflict category	Mean CGL per category (mm)	Minimum and maximum ages (years)	Mean age (years)
Region C	No conflict	461	14 and 16	15
	Road	479	13 and 16	14
Region D	No conflict	297	13 and 16	15
Region F	No conflict	275	16	16

7.4.6.4 Searsia lancea

The results of the distribution of the conflict categories of *S. lancea* (Table 7.63) reveal that the none of the trees in Regions D and F were in conflict and none of the trees were found in Region B. In Region A, 95% of the trees were not in conflict and the remaining 3.5% were in “overhead structures” and 1.5% in “sidewalks”. In Region C, 91.9% of the trees were found in “no conflict” and the remaining 9% in “overhead structures”.

Table 7.63: Percentage distribution of conflict for Searsia lancea

Conflict categories for ***Searsia lancea***	Region A	Region C	Region D	Region F
No conflict	95.0	91.9	100.0	100.0
Overhead structures	3.5	8.1	_	_
Sidewalk	1.5	_	_	_
Total percentage	100.0	100.0	100.0	100.0

The results for the mean CGL and age of the *S. lancea* trees in the conflict categories for each region (Table 7.64) show that the trees with the smallest mean CGL (467 mm) and the widest mean CGL (596 mm) as well as the youngest trees (12 years) and the oldest (16 years) were found in the “no conflict” category.

Table 7.64: Mean CGL and age per conflict category for Searsia lancea

Region	Conflict category	Mean CGL per category (mm)	Minimum and maximum ages (years)	Mean age (years)
Region A	No conflict	467.00	12	12
Region C	No conflict	574.00	13 and 15	14
Region D	No conflict	509.11	12 and 16	15
Region F	No conflict	596.00	16	16

7.4.7 Summary of the impact of land cover, land use and external factors on tree growth

The results of the impact of land use, land cover and the external factors on the growth of the individual tree species and in the regions are summarised to highlight the categories impacting the trees. The trees in Region A were planted later (mean age of 12 years) than the trees in Regions B, C and D (mean age of 14 years), but the oldest trees (mean age of 15 years) were found in Region F. The results did indicate that in Region F, most of the *C. africana, C. erythrophyllum* and *S. lancea* tree species were larger than in the other regions, but that the *O. europaea* subsp. *africana* trees in this region were smaller than in the other regions. Even though the trees in Region A were the youngest, they were not always the smallest.

The *C. africana* trees with the widest mean CGL were found in the “formal residential” land use category but were not the oldest trees. The *C. africana* trees with the second widest mean CGL were found in the “park” category and were one year older than the trees with the widest mean CGL. The trees with the smallest mean CGL were found in the “formal residential and commercial” category and were the youngest *C. africana* trees. The *C. erythrophyllum* trees with the widest mean CGL were found in the “formal residential” category and the trees with the second widest mean CGL were found in the “park” category, but neither of these were the oldest trees. The *C. erythrophyllum* trees with the smallest mean CGL were found in the “vacant land” category and were the youngest. The *O. europaea* subsp*. africana* trees with the widest mean CGL were found in the “formal residential” category but were not the oldest trees. The trees with the second widest mean CGL were found in the “park” category and were the oldest trees. The trees with the smallest mean CGL were found in the “open space maintained” category where *O. europaea* subsp. *africana* trees had the maximum mean age. The *S. lancea* trees with the widest mean CGL were found in the “park” category but were not the oldest trees and the trees with the second widest mean CGL were found in the “commercial and median” category and were the oldest trees. The trees with the smallest mean CGL were found in the “formal residential and median” category and were the oldest trees.

The *C. africana* trees with the widest mean CGL were found in the “bare soil” land cover category but were not the oldest trees. The *C. africana* trees with the second widest mean CGL were also found in the “bare soil” category and were the oldest trees. The trees with the smallest mean CGL were found in the “bare soil and paving” category and were not the youngest *C. africana* trees. The *C. erythrophyllum* trees with the widest mean CGL were found in the “bare soil” category and the trees with the second widest mean CGL were found in the “maintained grass” category, but neither of these were the oldest trees. The *C. erythrophyllum* trees with the smallest mean CGL were found in the “unmaintained grass” category and were the youngest trees. The *O. europaea* subsp*. africana* trees with the widest mean CGL were found in the “paving” category and the trees with the second widest mean CGL were found in the “bare soil” category, but neither of these were the oldest trees. The trees with the smallest mean CGL were found in the “maintained grass” category and were the oldest trees. The *S. lancea* trees with the widest mean CGL were found in the “paving” category but were not the oldest trees. The trees with the second widest mean CGL were found in the “unmaintained” category and were the oldest trees. The trees with the smallest mean CGL were found in the “paving and plant bed” category but were not the youngest trees.

The *C. africana* trees with the widest mean CGL needed structural pruning and trees with the second widest mean CGL were found in the “combination pruning” maintenance category; both these categories were the oldest trees. The trees with the smallest mean CGL did not need maintenance and were the youngest *C. africana* trees. The *C. erythrophyllum* trees with the widest and second widest mean CGL did not need maintenance but were not the oldest trees. The trees with the smallest mean CGL also did not need maintenance and were the youngest *C. erythrophyllum* trees. The *O. europaea* subsp. *africana* trees with the widest mean CGL needed structural pruning but were not the oldest trees. The trees with the second widest mean CGL did not need maintenance and were the oldest trees. The trees with the smallest mean CGL were found in the “pruning combination” category but were not the youngest trees. The *S. lancea* trees with the widest and second widest mean CGL did not need maintenance and were the oldest trees. The trees with the smallest mean CGL also did not need maintenance but were not the youngest trees.

Very few of the trees were impacted by pests and diseases. The *C. africana, C. erythrophyllum* and *O. europaea subsp. africana* trees with the widest mean CGL did not have any pests and diseases, but the *S. lancea* trees with the widest mean CGL had insects. The *C. africana* trees with the smallest mean CGL had insects and diseases and the *O. europaea* subsp*. africana* trees with the smallest mean CGL had insects and were not the smallest or largest trees. The *C. erythrophyllum* and *S. lancea* trees with the smallest mean CGL did not have any pests and diseases.

The *C. africana* trees with the widest mean CGL were found in the “unmaintained lawn” human influence category but were not the oldest trees. The *C. africana* trees with the second widest mean CGL were found in the “pedestrian traffic and maintained lawn” category and were oldest trees. The trees with the smallest mean CGL were found in the “unmaintained lawn” category and were the youngest trees. The *C. erythrophyllum* trees with the widest mean CGL were found in the “unmaintained lawn” category and the trees with the second widest mean CGL were found in the “maintained lawn” category, but neither of these were the oldest trees. The *C. erythrophyllum* trees with the smallest mean CGL were found in the “maintained lawn” category and were the youngest trees. The *O. europaea* subsp*. africana* trees with the widest mean CGL were found in the “pedestrian traffic” category and the trees with the second widest mean CGL were found in the “maintained lawn” category, but neither of these were the oldest trees. The trees with the smallest mean CGL were found in the “maintained lawn” category and were the oldest trees. The *S. lancea* trees with the widest mean CGL were found in the “pedestrian traffic” category but were not the oldest trees. The trees with the second widest mean CGL were found in the “rubble and maintained lawn” category and were the oldest trees. The trees with the smallest mean CGL were found in the “maintained lawn” category but were not the youngest trees.

Very few of the trees were impacted by conflict. The *C. africana* and *C. erythrophyllum* trees with the widest mean CGL were found in the “overhead structures” conflict category and were not the oldest trees. The *O. europaea* subsp*. africana* trees with the widest mean CGL were found in the “road” category and were also not the oldest trees?>>. The trees with the widest and smallest mean CGL were all found in the “no conflict” category.

7.5 Impact of land use, land cover and external factors on four tree species, in relation to VolCalc results

The sections above indicate possible relationships between the growth of the trees and the land use, land cover and external factors where these trees were found. However, the statistical significance of the results could not be determined. Therefore, hypothesis testing (Spearman’s rank correlation) was conducted to determine the significance of these results. The impact of land use, land cover and external factors for the four tree species mostly found (*C. africana, C. erythrophyllum, O. europaea* subsp*. africana* and *S. lancea*), in relation to the VolCalc results (tree height, height of maximum canopy diameter, height at first leaf, maximum canopy diameter, stem diameter at first leaf and tree volume) was determined individually and is presented for each of these species.

The VolCalc growth parameter data was grouped in ranges and ranked from low to high to enable analysis with the categorical land use, land cover and external factor data for each of the tree species and is displayed in Tables 7.65 to 7.68. The tables display all the ranges for the parameters of one species per graph, resulting in blank spaces which represents no data for that specific parameter.The sample size for the ranked VolCalc data for each species was as follows: *C. africana* (n = 359), *C. erythrophyllum* (n = 524), *O. europaea* subsp*. africana* (n = 267) and *S. lancea* (n = 287).

The ages of the trees in the study were not applied to this part of the study as it was seen from the section above that the youngest trees were not necessarily the smallest and the oldest trees were not necessarily the largest.

Table 7.65: VolCalc data ranges for Celtis africana

Celtis africana **n = 359**						
Range	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Volume (m^3)**
1	1.5 – 1.99	0.0 – 0.49	0.0 - 0.249	0.0 – 0.49	0.0 0 – 0.0249	0.0 – 4.99
2	2.0 – 2.49	0.5 – 0.99	0.25 – 0.499	0.5 – 0.99	0.025 – 0.0499	5.0 – 9.99
3	2.5 – 2.99	1.0 – 1.49	0.5 – 0.749	1.0 – 1.49	0.050 – 0.0749	10.0 – 14.99
4	3.0 – 3.49	1.5 – 1.99	0.75 – 0.999	1.5 – 1.99	0.075 – 0.0999	15.0 – 19.99
5	3.5 – 3.99	2.0 – 2.49	1.0 – 1.249	2.0 – 2.49	0.100 – 0.1249	20.0 – 24.99
6	4.0 – 4.49	2.5 – 2.99	1.25 – 1.499	2.5 – 2.99	0.125 – 0.1499	25.0 – 29.99
7	4.5 – 4.99	3.0 - 3.49	1.5 – 1.749	3.0 - 3.49	0.150 – 0.1749	30.0 – 34.99
8	5.0 – 5.49	3.5 – 3.99	1.75 – 1.999	3.5 – 3.99	0.175 – 0.1999	35.0 – 39.99
9	5.5 – 5.99	4.0 – 4.49	2.0 – 2.249	4.0 – 4.49	0.200 – 0.2249	40.0 – 44.99
10	6.0 – 6.49	4.5 – 4.99	2.25 – 2.499	4.5 – 4.99	0.225 – 0.2499	45.0 – 49.99
11	6.5 – 6.99		2.50 – 2. 749	5.0 – 5.49	0.250 – 0.2749	50.0 - 54.99
12	7.0 – 7.49		2.75 – 2.999	5.5 – 5.99	0.275 - 0.2999	55.0 - 59.99
13	7.5 - 7.99		3.0 – 3.249		0.300 - 0.3749	60.0 - 64.99
14			3.25 – 3.449		0.350 - 0.3749	65.0 - 69.99
15			3.50 – 3.749		0.375 - 0.3999	

Table 7.66: VolCalc data ranges for Combretum erythrophyllum

Combretum erythrophyllum **n = 524**						
Range	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Volume (m³)**
1	0.0 - 1.49	0.0 – 0.49	0.0 - 0.249	0.0 – 0.49	0.00 - 0.049	0.0 – 4.99
2	1.5 – 1.99	0.5 – 0.99	0.25 – 0.499	0.5 – 0.99	0.050 - 0.099	5.0 – 9.99
3	2.0 – 2.49	1.0 – 1.49	0.5 – 0.749	1.0 – 1.49	0.100 - 0.149	10.0 – 14.99
4	2.5 – 2.99	1.5 – 1.99	0.75 – 0.999	1.5 – 1.99	0.150 - 0.199	15.0 – 19.99
5	3.0 – 3.49	2.0 – 2.49	1.0 – 1.249	2.0 – 2.49	0.200 - 0.249	20.0 – 24.99
6	3.5 – 3.99	2.5 – 2.99	1.25 – 1.499	2.5 – 2.99	0.250 - 0.299	25.0 – 29.99
7	4.0 – 4.49	3.0 - 3.49	1.5 – 1.749	3.0 - 3.49	0.300 - 0.349	30.0 – 34.99
8	4.5 – 4.99	3.5 – 3.99	1.75 – 1.999	3.5 – 3.99	0.350 - 0.399	35.0 – 39.99
9	5.0 – 5.49	4.0 – 4.49	2.0 – 2.249	4.0 – 4.49	0.400 - 0.449	40.0 – 44.99
10	5.5 – 5.99	4.5 – 4.99	2.25 – 2.499	4.5 – 4.99	0.450 - 0.499	45.0 – 49.99
11	6.0 – 6.49		2.50 – 2. 749	5.0 – 5.49	0.500 - 0.549	50.0 - 54.99
12	6.5 – 6.99		2.75 – 2.999	5.5 – 5.99	0.550 - 0.599	55.0 - 59.99
13	7.0 – 7.49		3.0 – 3.249	6.0 - 6.49	0.600 - 0.649	
14	7.5 – 7.99		3.25 – 3.449	6.5 - 6.99	0.650 - 0.699	
15					0.700 - 0.749	
16					0.750 - 0.799	
17					0.800 - 0.849	
19					0.850 - 0.899	
20					0.900 - 0.949	
21					0.950 - 0.999	

Table 7.67: VolCalc data ranges for Olea europaea subsp. africana

Olea europaea **subsp.** ***africana*** **n = 267**						
Range	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Volume (m³)**
1	0.0 - 0.049	0.0 - 0.249	0.0 - 0.249	0.0 – 0.49	0.0 0 – 0.049	0.0 - 1.499
2	0.05 - 0.099	0.25 – 0.499	0.25 – 0.499	0.5 – 0.99	0.050 - 0.099	1.50 - 2.99
3	1.0 - 1.49	0.5 – 0.749	0.5 – 0.749	1.0 – 1.49	0.10 - 0.149	3.0 - 4.49
4	1.5 – 1.99	0.75 – 0.999	0.75 – 0.999	1.5 – 1.99	0.150 - 0.199	4.5 - 5.99
5	2.0 – 2.49	1.0 – 1.249	1.0 – 1.249	2.0 – 2.49	0.200 - 0.249	6.0 - 7.49
6	2.5 – 2.99	1.25 – 1.499	1.25 – 1.499	2.5 – 2.99	0.250 - 0.299	7.5 - 8.99
7	3.0 – 3.49	1.5 – 1.749	1.5 – 1.749	3.0 - 3.49	0.300 - 0.349	9.0 - 10.49
8	3.5 – 3.99	1.75 – 1.999	1.75 – 1.999	3.5 – 3.99	0.350 - 0.399	10.5 - 11.99
9	4.0 – 4.49	2.0 – 2.249	2.0 – 2.249	4.0 – 4.49	0.400 - 0.449	12.0 - 13.49
10	4.5 – 4.99	2.25 – 2.499	2.25 – 2.499	4.5 – 4.99	0.450 - 0.499	13.5 - 14.99
11	5.0 – 5.49	2.50 – 2. 749	2.50 – 2. 749		0.500 - 0.549	15.0 - 16.49
12		2.75 – 2.999	2.75 - 2.999		0.550 - 0.599	16.5 - 17.99
13		3.0 – 3.249			0.600 - 0.649	18.0 - 19.49
14		3.25 – 3.449			0.650 - 0.699	19.5 - 20.99
15		3.50 – 3.749			0.700 - 0.749	21.0 - 22.49
16					0.750 - 0.799	22.5 - 23.99
17					0.800 - 0.849	
18					0.850 - 0.899	

Table 7.68: VolCalc data ranges for Searsia lancea

Searsia lancea **n = 287**						
Range	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Volume (m³)**
1	1.5 – 1.99	0.0 - 0.249	0.0 - 0.249	0.0 – 0.49	0.0 0 – 0.049	0.0 – 4.99
2	2.0 – 2.49	0.25 – 0.499	0.25 – 0.499	0.5 – 0.99	0.050 - 0.099	5.0 – 9.99
3	2.5 – 2.99	0.5 – 0.749	0.5 – 0.749	1.0 – 1.49	0.10 - 0.149	10.0 – 14.99
4	3.0 – 3.49	0.75 – 0.999	0.75 – 0.999	1.5 – 1.99	0.150 - 0.199	15.0 – 19.99
5	3.5 – 3.99	1.0 – 1.249	1.0 – 1.249	2.0 – 2.49	0.200 - 0.249	20.0 – 24.99
6	4.0 – 4.49	1.25 – 1.499	1.25 – 1.499	2.5 – 2.99	0.250 - 0.299	25.0 – 29.99
7	4.5 – 4.99	1.5 – 1.749	1.5 – 1.749	3.0 - 3.49	0.300 - 0.349	30.0 – 34.99
8	5.0 – 5.49	1.75 – 1.999	1.75 – 1.999	3.5 – 3.99	0.350 - 0.399	35.0 – 39.99
9	5.5 – 5.99	2.0 – 2.249		4.0 – 4.49	0.400 - 0.449	40.0 – 44.99
10		2.25 – 2.499		4.5 – 4.99	0.450 - 0.499	45.0 – 49.99
11		2.50 – 2. 749		5.0 – 5.49	0.500 - 0.549	50.0 - 54.99
12		2.75 – 2.999		5.5 – 5.99		55.0 - 59.99
13		3.0 – 3.249				
14		3.25 – 3.449				
15		3.50 – 3.749				
16		3.75 - 4.99				

Using the ranges of the VolCalc data, frequency tables were generated using SPSS, and Spearman's rank correlation was used to determine the strength of the relationship between paired datasets. Spearman's rank correlation is a non-parametric test to find the relationship between two ordered categorical variables. In this study, it was used as a statistical measure of the strength of a monotonic relationship of non-parametric data to determine correlations between the data groups. An example of the data is presented in the frequency distribution graph (Figure 7.14) and the non-monotonic relationship of the variables is clear. It illustrates the non-monotonic relationship between the number of *Celtis africana* trees in the study and the height of these trees. An increase in the independent variable (number of trees) did not produce an increase in the dependent variable (tree height ranges), as low numbers of trees are found in the ranges for small tree heights (range 1 to 3) as is found with ranges of large trees (range 10 to 14). The number of trees did not increase as the tree height ranges increased, resulting in a shape resembling a bell shape graph, which is non-monotonic.

With regard to the Spearman's rank coefficient results, the outcome of the correlation analysis is a +/- rho value, with rho indicating the magnitude of the relationship and the sign +/- indicating the direction of the relationship. For this study, a rho of 0.1 to 0.3 was considered a weak relationship, 0.3 to 0.5 a moderate relationship and over 0.5 a strong relationship (Conway & Bourne, 2013).

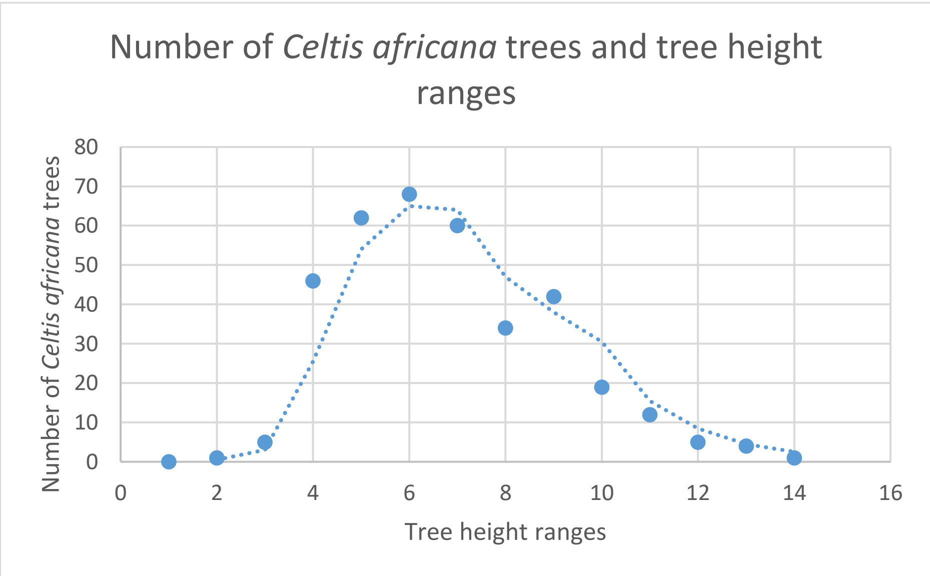


Figure 7.14: Monotonic relationship between number of trees and tree height ranges of Celtis africana

The other variables in the study presented similar diagrams and therefore correlation coefficient was the correct measure to use.

The Kruskal-Wallis H test is also a rank-based non-parametric test. In this study, it was used to test for significant differences between the VolCalc parameters and variables of land use, land cover and external factors.

7.5.1 Impact of land use, land cover and external factors on *Celtis africana*

7.5.1.1 Frequencies of the VolCalc parameters

Frequency distributions were used to describe the VolCalc parameters. There were 359 of the *C. africana* trees (n = 885) in the study with VolCalc data.

The VolCalc parameter frequency distribution results (Table 7.69) show that the *C. africana* trees with a height range of 3.5 – 3.99 m had the highest frequency (18.9%; n = 68) and those with a height range of 1.5 – 1.99 m and 7.5 – 7.99 m had the lowest (0.3%; n = 1 each). The trees with a height of maximum canopy diameter range of 2.5 – 2.99 m had the highest frequency (28.7%; n = 103) and those with a range of 0.0 – 0.49 m had the lowest (0.3%; n = 1). The trees with a height at first leaf range of 1.25 – 1.499 m had the highest frequency (23.1%; n = 83) and those with a range of 3.50 – 3.749 m had the lowest (0.3%; n = 1). The trees with a maximum canopy diameter range of 2.5 – 2.99 m had the highest frequency (25.1%; n = 90) and those with a range of 5.5 – 5.99 m had the lowest (0.3%; n = 1). The trees with a stem diameter at first leaf range of 0.100 – 0.1249 m had the highest frequency (31.2%; n = 76) and those with the lowest frequency (0.3%; n = 1) were in three ranges of 0.00 – 0.0249 m, 0.275 - 0.2999 m and 0.300 - 0.349 m. Most of the trees (31.2%; n = 112) were in the volume range of 0.0 – 4.99 m^3 and those with the lowest frequency (0.3%; n = 1) were in two ranges of 40.0 – 44.99 m and 65.0 - 69.99 m.

Table 7.69: VolCalc parameter frequency distributions for Celtis africana

Celtis africana **(n = 359)**						
Range	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Volume (m^3)**
1	1	1	10	1	1	112
2	5	2	10	1	24	109
3	46	29	20	10	71	68
4	62	83	34	38	73	32
5	68	103	83	64	76	18
6	60	70	67	90	44	6
7	34	36	55	78	26	6
8	42	29	42	36	15	6
9	19	6	19	25	15	1
10	12	1	10	10	5	0
11	5		6	5	4	0
12	4		2	1	1	0
13	1		1		1	0
14					3	1
15					1	

Except for volume, the frequency distribution of the number of *C. africana* for the ranges of all the other VolCalc parameters is similar (Table 7.69) and can be shaped as a norman distribution curve and seen in Figure 7.14, which illustrates the non-monotonic relationship. The frequency distribution is very low across the small and very high ranks (0.3%; n = 1 each) with a range of 1.5 – 1.99 m (shortest tree) and 7.5 – 7.99 m (tallest tree) as highlighted in orange in Table 7.69. The frequency distribution of the number of trees is the highest between the 4th and 6th range. The volume parameter frequency distribution has the highest rank in the lowest range of 0.0 – 4.9 m^3 (31.2%; n = 112) and the second lowest range of 5.0 – 9.99 m^3 (30.4%; n = 109) - highlighted in green. The frequency distribution ranks decrease as the volume range increases and the lowest ranks (0.3%; n = 1 each) are found in the highest two ranges: 40.0 – 44.99 m^3 and 65.0 - 69.99 m^3. This indicates that most of the trees were small to medium across the parameters. The orange ranges highlight that there were small numbers of trees that were either very small or large.

The frequency distribution of land use, land cover and external factors (Table 7.70) indicates that the highest frequency distributions of the *C. africana* trees were in the “formal residential” (27.0%; n = 97) land use category, the “maintained grass” (45.1%; n = 162) land cover category, the “no pests and diseases” (80.8%; n = 290) category, the “no maintenance” (75.2%; n = 270) category, the “no conflict” (81.6%; n = 293) category and the “maintained lawn” (39.3%; n = 141) human influence category.

Table 7.70: Frequency distribution of Celtis africana *across land use, land cover and external factors*

***Celtis africana* (n = 359)**						
Range	**Land use**	**Land cover**	**Pests and diseases**	**Maintenance needs**	**Conflict**	**Human influence**
1	97	162	290	270	293	
2	0	45	66	1	28	3
3	24	60	3	0	0	0
4	0	27		51	2	20
5	0	2		5	27	0
6	0	20		3	9	2
7	20	0		0		141
8	83	0		10		140
9	0	0		1		0
10	41	0		6		0
11	0	0		2		14
12	18	1		3		6
13	20	41		3		10
14	9	0		2		21
15	0	1				0
16	5					0
17	3					2
18	3					
19	2					
20	20					
21	0					
22	14					

7.5.1.2 Relationships/correlations

The relationships or correlations between land use, land cover and external factors and each of the VolCalc variables for *C. africana* tree species were analysed to determine the impact of land use, land cover and external factors on the VolCalc growth parameters of the species.

Table 7.71: Spearman's rank correlation coefficient for VolCalc parameters and land use, land cover and external factor variables for Celtis africana

Celtis africana				
VolCalc parameters	**Variables**	**N**	**Spearman's rank correlation (rho)**	**Probability**
Tree height (m)	Land use	359	-0.294**	p = 0.001
	Land cover	359	-0.225**	p = 0.001
	Pests and diseases	359	-0.155**	P = 0.003
	Maintenance needs	359	-0.218**	p = 0.001
	Conflict	359	0.001	P = 0.995
	Human influence	359	-0.254**	p = 0.001
Height of maximum canopy diameter (m)	Land use	359	-0.189**	p = 0.001
	Land cover	359	-0.105*	P = 0.046
	Pests and diseases	359	-0.209**	p = 0.001
	Maintenance needs	359	-0.228**	p = 0.001
	Conflict	359	-0.065	P = 0.222
	Human influence	359	-0.203**	p = 0.001
Height at first leaf (m)	Land use	359	-0.001	P = 0.988
	Land cover	359	-0.001	P = 0.980
	Pests and diseases	359	-.149**	P = 0.005
	Maintenance needs	359	-.232**	P = 0.001
	Conflict	359	-.113*	P = 0.032
	Human influence	359	-0.098	P = 0.063
Maximum canopy diameter (m)	Land use	359	-0.373**	P = 0.001
	Land cover	359	-0.076	p = 0.148
	Pests and diseases	359	-0.078	P = 0.141
	Maintenance needs	359	-0.173**	P = 0.001
	Conflict	359	0.113*	P = 0.033
	Human influence	359	-0.139**	P = 0.009
Stem diameter at first leaf (m)	Land use	359	-0.436**	P = 0.001
	Land cover	359	-0.189**	P = 0.001
	Pests and diseases	359	-0.161**	P = 0.002
	Maintenance needs	359	-0.178**	P = 0.001
	Conflict	359	0.178**	P = 0.001
	Human influence	359	-0.249**	P = 0.001
Volume (m^3)	Land use	359	-0.436**	P = 0.001
	Land cover	359	-0.211**	P = 0.001
	Pests and diseases	359	-0.141**	P = 0.008
	Maintenance needs	359	-0.168**	P = 0.001
	Conflict	359	0.101	P = 0.056
	Human influence	359	-0.211**	P = 0.001

*N = number of trees in sample; rho value with ** indicates significance at 0.001 and * at 0.01*

The Spearman's rank correlation coefficient (Table 7.71) indicates that most of the correlations between tree height and land use, land cover and external factor variables were weak and negative. Most of these relationships were found to be statistically significant. A negative and significant correlation was found between tree height and land use (rho = -0.294; p = 0.001), human influence (rho = -0.254; p = 0.001), land cover (rho = -0.225; p = 0.001 and maintenance needs (rho = -0.218; p = 0.001). Pests and diseases (rho = -0.155; p = 0.003) also showed a negative and significant correlation with tree height. However, a positive and non-significant relationship was found between tree height and conflict (rho = 0.001; p = 0.995).

It can be concluded that there are significant differences in tree height relative to the land use, land cover, human influence, maintenance needed and pest and disease dependent variables.

The Spearman's rank correlation coefficient for height of maximum canopy diameter and land use, land cover and external factor variables (Table 7.71) indicates that the correlations were weak and negative. However, several of these relationships were found to be statistically significant. A negative and significant correlation was found between height of maximum canopy diameter and maintenance needs (rho = -0.228; p = 0.001), pests and diseases (rho = -0.209; p = 0.001), human influence (rho = -0.203; p = 0.001) and land use (rho = -0.189; p = 0.001). Land cover (rho = -0.105; p = 0.046) showed a very weak, negative but significant correlation with height of maximum canopy diameter, and a negative and non-significant relationship was found between height of maximum canopy diameter and conflict (rho = -0.065; p = 0.222).

The Spearman's rank correlation coefficient for height at first leaf and land use, land cover and external factor variables (Table 7.71) shows that the correlations were negative, and some were found to be statistically significant. A negative, weak and significant correlation was found between height at first leaf and maintenance needs (rho = -0.232; p = 0.001) and pests and diseases (rho = -0.149; p = 0.001). Conflict (rho = -0.113; p = 0.032) showed a very weak, negative but significant correlation with height at first leaf. Human influence (rho = -0.098; p = 0.063) showed a negative and non-significant relationship with height at first leaf, as did land use (rho = -0.001; p = 0.980) and land cover (rho = -0.001; p = 0.988).

The Spearman's rank correlation coefficient for maximum canopy diameter and land use, land cover and external factor variables is shown in Table 7.71. All the correlations between maximum canopy diameter and land use, land cover and external factor variables were negative and most of them were weak. Some of these relationships were found to be statistically significant. A moderate, negative and significant correlation was found between maximum canopy diameter and land use (rho = -0.373; p = 0.001). A weak, negative and significant correlation was found between maintenance needs (rho = -0.173; p = 0.001) and human influence (rho = -0.139; p = 0.009). A very weak, negative but significant correlation was found between conflict (rho = 0.113; p = 0.033) and maximum canopy diameter. A non-significant relationship was found between maximum canopy diameter, pests and diseases (rho = -0.078; p = 0.141) and land cover (rho = -0.076; p = 0.148).

The Spearman's rank correlation coefficient for stem diameter at first leaf and land use, land cover and external factor variables indicates that most of the correlations were negative and weak (Table 7.71), but these relationships were found to be statistically significant. A moderate, negative and significant correlation was found between stem diameter at first leaf and land use (rho = -0.436; p = 0.001). A weak, negative and significant correlation was found between stem diameter at first leaf and human influence (rho = -0.249; p = 0.001), land cover (rho = -0.189; p = 0.001), maintenance needs (rho = -0.178; p = 0.001) and pests and diseases (rho = -0.161; p = 0.002). However, a positive and significant relationship was found between stem diameter at first leaf and conflict (rho = 0.178; p = 0.001).

The Spearman's rank correlation coefficient for volume and land use, land cover and external factor variables was negative and weak, but most of these relationships were found to be statistically significant (Table 7.71). A moderate, negative and significant correlation was found between volume and land use (rho = -0.436; p = 0.001). A weak, negative and significant correlation was found between volume and land cover (rho = -0.211; p = 0.001) and human influence (rho = -0.211; p = 0.001). A weak, negative and significant correlation was found between volume and maintenance needs (rho = -0.168; p = 0.001) and pests and diseases (rho = -141; p = 0.008). However, a positive and non-significant relationship was found between volume and conflict (rho = 0.101; p = 0.056).

7.5.2 Impact of land use, land cover and external factors on *Combretum erythrophyllum*

7.5.2.1 Frequencies of the VolCalc parameters

Frequency distributions were used to describe the VolCalc parameters. There were 524 of the *C. erythrophyllum* trees (n = 874) in the study with VolCalc data. The VolCalc parameter frequency distribution results (Table 7.72) indicate that *C. erythrophyllum* trees with a height range of 2.5 – 2.99 m had the highest frequency (17.2%; n = 90) and those with a height range of 7.5 - 7.99 m had the lowest (0.4%; n = 2). The trees with a height of maximum canopy diameter range of 2.0 – 2.49 m had the highest frequency (22.9%; n = 120) and those with a range of 4.5 – 4.99 m had the lowest (0.2%; n = 1). The trees with a height at first leaf of 1.25 – 1.499 m had the highest frequency (19.7%; n = 103) and those with a range of 3.25 – 3.449 m had the lowest (0.2%; n = 1). The trees with a maximum canopy diameter range of 1.5 – 1.99 m had the highest frequency (21.6%; n = 113) and those with a range of 6.5 - 6.99 m had the lowest (0.2%; n = 1). The trees with a stem diameter at first leaf range of 0.050 - 0.099 m had the highest frequency (17.0%; n = 89) and those with a range of 0.950 - 0.999 m had the lowest (0.8%; n = 4). Most of the trees (51.7%; n = 271) were in the volume range of 0.0 –

4.99 m^3 and those with the lowest frequency (0.8%; n = 4) were in two ranges of 40.0 – 44.99 m and 55.0 - 59.99 m.

Table 7.72: VolCalc parameter frequency distributions for Combretum erythrophyllum

***Combretum erythrophyllum* (n = 524)**						
Range	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Volume (m³)**
1	6	11	0	4	57	271
2	28	52	14	30	89	101
3	46	115	39	62	57	58
4	90	120	74	113	22	33
5	88	112	101	87	17	18
6	71	71	103	80	12	12
7	78	30	70	64	18	8
8	41	12	52	31	14	5
9	35	1	29	27	24	2
10	22		25	14	25	5
11	7		10	6	24	4
12	7		6	5	28	2
13	3		1	0	25	4
14	2			1	28	
15					23	
16					18	
17					16	
18					0	
19					17	
20					6	
21					4	

The two highest frequency results are highlighted in green and the lowest are highlighted in orange in Table 7.72. From this visual display, it can be deduced that except for stem diameter at first leaf and volume, the frequency distribution of the number of trees for the ranges of all the other VolCalc parameters is similar (Table 7.72). The frequency distribution is low across the low ranges and very high ranges - highlighted in orange in Table 7.72. The frequency distribution of the number of trees is the highest between the 3rd and 6th ranges. The height at first leaf and volume parameter frequency distributions have the highest rank in the very low ranges - highlighted in green. The frequency distribution ranks decrease as the height at first leaf and volume ranges increase and the lowest ranks are found in the highest two ranges. This indicates that most of the trees were small to medium in size. The orange ranges highlight that there were small numbers of trees that were either very small or large.

Table 7.73: Frequency distribution of Combretum erythrophyllum *across land use, land cover and external factors*

***Combretum erythrophyllum* (n = 524)**					
Range	**Land use**	**Land cover**	**Pests and diseases**	**Maintenance needs**	**Conflict**
1	143	220	504	190	445
2	0	104	19	1	16
3	42	96	0	6	0
4	21	21	1	89	19
5	0	7		11	44
6	2	7		7	
7	0	0		3	
8	113	0		154	
9	46	15		3	
10	38	19		13	
11	0	1		8	
12	22	0		1	
13	0	13		4	
14	0	1		13	
15	16	0		4	
16	0	20		8	
17	0			6	
18	0				
19	0				
20	0				
21	0				
22	13				
23	61				
24	7				

The frequency distribution of land use, land cover and external factors (Table 7.73) indicates that the highest frequency distribution of the *C. erythrophyllum* trees was in the "formal residential" (27.3%; n = 143) land use category, in the "maintained grass" (42.0%; n = 220) land cover category, did not have any pests and diseases (96.2%; n = 504), did not require any maintenance (36.3%; n = 190), was in the "no conflict" category (84.9%; n = 445) and was in the "maintained" (39.3%; n = 141) human influence category.

7.5.2.2 Relationships/correlations

The relationships or correlations between land use, land cover and external factors and each of the VolCalc variables for *C. erythrophyllum* tree species were analysed to determine the impact of land use, land cover and external factors on the VolCalc growth parameters of the species.

The Spearman's rank correlation coefficient for tree height and land use, land cover and external factor variables (Table 7.74) indicates that most of the correlations were weak. Despite this, some of these relationships were found to be statistically significant. A weak, positive and significant correlation was found between tree height and conflict (rho = 0.229; p = 0.000). A weak, negative and significant correlation was found between tree height and maintenance needs (rho = -0.165; p = 0.000). Pests and diseases (rho = -0.089; p = 0.042) also showed a negative and significant correlation with tree height. A very weak, positive but non-significant relationship was found between tree height and land use (rho = 0.070; p = 0.110) and land cover (rho = 0.065; p = 0.139).

Table 7.74: Spearman's rank correlation coefficient for VolCalc parameters and tree height and land use, land cover and external factor variables for Combretum erythrophyllum

Combretum erythrophyllum				
VolCalc parameters	**Variables**	**N**	**Spearman's rank correlation (rho)**	**Probability**
Tree height (m)	Land use	524	0.070	p = 0.110
	Land cover	524	0.065	p = 0.139
	Pests and diseases	524	-0.089*	p = 0.042
	Maintenance needs	524	-0.165**	p = 0.001
	Conflict	524	0.229**	p = 0.001
Height of maximum canopy diameter (m)	Land use	524	0.094*	p = 0.031
	Land cover	524	0.027	p = 0.543
	Pests and diseases	524	-0.125**	p = 0.004
	Maintenance needs	524	-0.184**	p = 0.001
	Conflict	524	0.188**	p = 0.001
Height at first leaf (m)	Land use	524	0.197**	p = 0.001
	Land cover	524	0.034	p = 0.435
	Pests and diseases	524	0.034	p = 0.014
	Maintenance needs	524	0.197**	p = 0.001
	Conflict	524	0.048	p = 0.274
Maximum canopy diameter (m)	Land use	524	-0.067	p = 0.127
	Land cover	524	0.124**	p = 0.004
	Pests and diseases	524	-0.094*	p = 0.031
	Maintenance needs	524	-0.085	p = 0.054
	Conflict	524	0.242**	p = 0.001
Stem diameter at first leaf (m)	Land use	524	0.026	p = 0.550
	Land cover	524	0.106*	p = 0.015
	Pests and diseases	524	0.035	p = 0.427
	Maintenance needs	524	-0.166**	p = 0.001
	Conflict	524	0.136**	p = 0.002
Volume (m^3)	Land use	524	-0.109*	p = 0.013
	Land cover	524	0.095*	p = 0.030
	Pests and diseases	524	-0.093*	p = 0.033
	Maintenance needs	524	-0.095*	p = 0.031
	Conflict	524	0.250**	p = 0.001

*N = number of trees in sample; rho value with ** indicates significance at 0.001 and * at 0.01*

The Spearman's rank correlation coefficient (Table 7.74) shows that the correlations between height of maximum canopy diameter and land use, land cover and external factor variables were mostly weak. However, some of these relationships were found to be statistically significant. A positive and significant correlation was found between height of maximum canopy diameter and conflict (rho -0.188; p = 0.001) and a negative and significant correlation was found between height of maximum canopy diameter and maintenance needs (rho = -0.184; p = 0.001) and pests and diseases (rho = -0.125; p = 0.004). Land use (rho = -0.094; p = 0.031) showed a very weak positive but significant correlation with height of maximum canopy diameter. Land cover (rho = 0.027; p = 0.543) showed a positive but non-significant relationship with height of maximum canopy diameter.

The Spearman's rank correlation coefficient for height at first leaf and land use, land cover and external factor variables (Table 7.74) indicates that the correlations were positive, and some were found to be statistically significant. A weak and significant correlation was found between height at first leaf, maintenance needs (rho = 0.197; p = 0.001) and land use (rho = 0.197; p = 0.001). Conflict (rho = 0.048; p = 0.274), land cover (rho = 0.034; p = 0.435) and pests and diseases (rho = 0.034; p = 0.014) showed a positive but non-significant correlation with height at first leaf.

The Spearman's rank correlation coefficient for maximum canopy diameter and land use, land cover and external factor variables (Table 7.74) shows that some of the correlations were positive and weak. Some of these relationships were found to be statistically significant. A moderate, negative and significant correlation was found between maximum canopy diameter and land use (rho = -0.373; p = 0.001). A positive and significant correlation was found between conflict (rho = 0.242; p = 0.001) and land cover (rho = 0.124; p = 0.004). A very weak, negative but significant correlation was found between pests and diseases (rho = -0.094; p = 0.031) and maximum canopy diameter. A negative and non-significant relationship was found between maximum canopy diameter and land use (rho = -0.067; p = 0.127) and maintenance needs (rho = -0.085; p = 0.054).

The Spearman's rank correlation coefficient for stem diameter at first leaf and land use, land cover and external factor variables indicates that most of the correlations were positive and some were weak (Table 7.74). Some of these relationships were found to be statistically significant. A weak, negative and significant correlation was found between stem diameter at first leaf and maintenance needs (rho = -0.166; p = 0.001). A weak, positive and significant correlation was found between stem diameter at first leaf and conflict (rho = 0.136; p = 0.002) and a very weak, positive relationship was found between stem diameter at first leaf and land cover (rho = 0.106; p = 0.015). Land use (rho = 0.026; p = 0.550) and pests and diseases (rho

= 0.035; p = 0.427) showed a positive but non-significant relationship with stem diameter at first leaf.

The Spearman's rank correlation coefficient for volume and land use, land cover and external factor variables (Table 7.74) shows that most of the correlations were negative and very weak. However, these relationships were found to be statistically significant. A weak, positive and significant correlation was found between volume and conflict (rho = 0.250; p = 0.001). A very weak, negative and significant correlation was found between volume and land use (rho = -.0109; p = 0.013), pests and diseases (rho = -0.093; p = 0.033) and maintenance needs (rho = -0.95; p = 0.031). A very weak, positive and significant correlation was found between volume and land cover (rho = 0.095; p = 0.030).

7.5.3 Impact of land use, land cover and external factors on *Olea europaea* subsp*. africana*

7.5.3.1 Frequencies of the VolCalc parameters

Frequency distributions were used to describe the VolCalc parameters. There were only 267 of the *O. europaea* subsp*. africana* trees (n = 414) in the study with VolCalc data. The VolCalc parameter frequency distribution results (Table 7.75) indicate that *O. europaea* subsp*. africana* trees with a height range of 2.5 – 2.99 m had the highest frequency (34.1%; n = 91) and those with a height range of 0.0 - 0.049 m and 0.05 - 0.099 m had the lowest (0.4%; n = 1). The trees with a height of maximum canopy diameter range of 1.5 – 1.749 m had the highest frequency (24.0%; n = 64) and those with ranges of 0.0 - 0.249 m and 3.50 – 3.749 m had the lowest (0.4%; n = 1). The trees with a height at first leaf range of 1.0 – 1.249 m had the highest frequency (24.7%; n = 66) and those with a range of 0.0 - 0.249 m and 2.25 – 2.499 m had the lowest (0.4%; n = 1). The trees with a maximum canopy diameter range of 2.0 – 2.49 m had the highest frequency (21.0%; n = 56) and those with a range of 0.0 – 0.49 m had the lowest (0.4%; n = 1). The trees with a stem diameter at first leaf range of 0.050 - 0.099 m had the highest frequency (54.1%; n = 138) and those with the lowest frequency (0.4%; n = 1 each) were found in four ranges: 0.450 - 0.499 m, 0.500 - 0.549 m, 0.600 - 0.649 m and 0.850 - 0.899 m. Most of the trees (28.1%; n = 75) were in the volume range of 0.0 – 1.499 m^3 and those with the lowest frequency (0.4%; n = 1 each) were in two ranges of 18.0 - 19.49 m and 22.5 - 23.99 m.

Table 7.75: VolCalc parameter frequency distribution results for Olea europaea subsp. africana

***Olea europaea* subsp. *africana* (n = 267)**						
Range	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at height at first leaf (m)**	**Volume (m^3)**
1	1	0	1	1	29	75
2	1	0	24	15	138	53
3	24	1	42	44	54	37
4	62	4	61	55	17	30
5	91	20	66	56	7	18
6	49	33	44	52	9	14
7	30	64	17	28	4	9
8	6	33	7	14	5	10
9	3	46	4	2	0	11
10	1	34	1		1	4
11		14			1	2
12		10			0	2
13		7			1	1
14		0			0	0
15		1			0	0
16					0	1
17					0	
18					1	

The highest two frequency results are highlighted in green and the lowest are highlighted in orange in Table 7.75. From this visual presentation, it can be deduced that except for height of maximum canopy diameter, stem diameter at first leaf and volume, the frequency distribution of the number of trees for the ranges of all of the other VolCalc parameters is similar (Table 7.75). The frequency distribution is low across the low ranges and very high ranges - highlighted in orange in table 7.75. The frequency distribution of the number of trees is the highest between the 4th and 5th ranges. The height of maximum canopy diameter frequency distribution was the highest in the 9th range, confirming the wide crown shape typical of the *O. europaea* subsp. *africana*. The stem diameter at first leaf and volume parameter frequency distributions have the highest rank in the very low ranges - highlighted in green. The frequency distribution ranks decrease as the height at first leaf and volume ranges increase and the lowest ranks are found in the highest two ranges. This indicates that most of the trees were small to medium in size. The orange ranges highlight that there were small numbers of trees that were either very small or large.

The frequency distribution of land use, land cover and external factors (Table 7.76) indicates that the highest frequency distribution of the *O. europaea* subsp. *africana* trees was in the "formal residential" (34.1%; n = 91) land use category, in the "maintained grass" (30.7%; n =

82) land cover category, did not have any pests and diseases (67.8%; n = 181), did not require any maintenance (41.9%; n = 112), did not present any conflict (85.0%; n = 227) and was in the “maintained” (40.1%, n = 107) human influence category.

Table 7.76: Frequency distribution of Olea europaea subsp. africana *across land use, land cover and external factors*

***Olea europaea* subsp. *africana* (n = 267)**						
Range	**Land use**	**Land cover**	**Pests and diseases**	**Maintenance needs**	**Conflict**	**Human influence**
1	82	91	181	112	227	17
2	4	27	18	1	16	0
3	28	90	0	0	1	0
4	0	34	28	37	14	9
5	0	0	40	10	9	0
6	0	1		7		2
7	0	0		2		107
8	70	20		51		21
9	20	3		2		0
10	0	0		7		1
11	0	0		4		0
12	6	0		0		0
13	2	0		0		0
14	0	0		22		33
15	0	0		0		16
16	0	1		2		41
17	0			9		1
18	6					19
19	0					
20	0					
21	0					
22	16					
23	33					

7.5.3.2 Relationships/correlations

The relationships or correlations between land use, land cover and external factors and each of the VolCalc variables for *O. europaea* subsp. *africana* tree species were analysed to determine the impact of land use, land cover and external factors on the VolCalc growth parameters of the species.

Table 7.77: Spearman's rank correlation coefficient for VolCalc parameters and tree height and land use, land cover and external factor variables for Olea europaea subsp. africana

Olea europaea* subsp. *africana				
VolCalc parameters	**Variables**	**N**	**Spearman's rank correlation (rho)**	**Probability**
Tree height (m)	Land use	267	-0.213**	p = 0 001
	Land cover	267	-0.013	p = 0.836
	Pests and diseases	267	-0.017	p = 0.786
	Maintenance needs	267	0.049	p = 0.430
	Conflict	267	0.238**	p = 0 001
	Human influence	267	0.019	p = 0.762
Height of maximum canopy diameter (m)	Land use	267	-0.134*	p = 0.029
	Land cover	267	-0.137*	p = 0.025
	Pests and diseases	267	-0.012	p = 0.843
	Maintenance needs	267	0.098	p = 0.111
	Conflict	267	0.089	p = 0.147
	Human influence	267	0.180**	p = 0.003
Height at first leaf (m)	Land use	267	0.105	p = 0.086
	Land cover	267	-0.327**	p = 0 001
	Pests and diseases	267	-0.018	p = 0.772
	Maintenance needs	267	0.123*	p = 0.045
	Conflict	267	-0.107	p = 0.080
	Human influence	267	0.230**	p = 0.001
Maximum canopy diameter (m)	Land use	267	-0.412**	p = 0.001
	Land cover	267	0.162**	p = 0.008
	Pests and diseases	267	-0.019	p = 0.759
	Maintenance needs	267	-0.052	p = 0.398
	Conflict	267	0.360**	p = 0.001
	Human influence	267	-0.174**	p = 0.004
Stem diameter at first leaf (m)	Land use	267	-0.251**	p = 0.001
	Land cover	267	0.042	p = 0.495
	Pests and diseases	267	-0.128*	p = 0.037
	Maintenance needs	267	-0.104	p = 0.091
	Conflict	267	0.343**	p = 0 001
	Human influence	267	-0.163**	p = 0.008
Volume (m^3)	Land use	267	-0.395**	p = 0 001
	Land cover	267	0.150*	p = 0.014
	Pests and diseases	267	-0.018	p = 0.773
	Maintenance needs	267	-0.021	p = 0.733
	Conflict	267	0.384**	p = 0.001
	Human influence	267	0-.137*	p = 0.025

*N = number of trees in sample; rho value with ** indicates significance at 0.001 and * at 0.01.*

The Spearman's rank correlation coefficient for tree height and land use, land cover and external factor variables (Table 7.77) shows that most of the correlations were not significant. Two of the relationships were found to be weak but statistically significant. A weak, positive and significant correlation was found between tree height and conflict (rho = 0.238; p = 0.001). A weak, negative and significant correlation was found between tree height and land use (rho

= -0.213; p = 0.001). Pests and diseases (rho = -0.017; p = 0.786) and land cover (rho = -0.013; p = 0.836) showed a negative and non-significant correlation with tree height. A positive and non-significant relationship was found between tree height and maintenance needs (rho = 0.049; p = 0.430) and human influence (rho = 0.019; p = 0.762).

The Spearman's rank correlation coefficient for height of maximum canopy diameter and land use, land cover and external factor variables (Table 7.77) indicates that some of the correlations were weak but significant. A weak, positive and significant correlation was found between height of maximum canopy diameter and human influence (rho = -0.180; p = 0.003). A negative, very weak but significant correlation was found between height of maximum canopy diameter and land use (rho = -0.134; p = 0.029). A negative but non-significant relationship was found between height of maximum canopy diameter and pests and diseases (rho = -0.012; p = 0.843) and a positive and non-significant relationship was found between height of maximum canopy diameter and conflict (rho = 0.089; p = 0.147) and maintenance needs (rho = 0.098; p = 0.111).

The Spearman's rank correlation coefficient for height at first leaf and land use, land cover and external factor variables indicates that some of the correlations were positive and some were found to be statistically significant (Table 7.77). A negative, moderate and significant correlation was found between height at first leaf and land cover (rho = 0.327; p = 0.001). A positive, weak and significant relationship was found between height at first leaf and human influence (rho = 0.230; p = 0.001). A positive, very weak and significant relationship was found between height at first leaf and maintenance needs (rho = 0.123; p = 0.045). Conflict (rho = -0.107; p = 0.080), land use (rho = 0.105; p = 0.086) and pests and diseases (rho = -0.018; p = 0.772) showed a non-significant correlation with height at first leaf. Land use and pests and diseases showed a positive relationship, but land use and conflict showed a negative relationship.

The Spearman's rank correlation coefficient for maximum canopy diameter and land use, land cover and external factor variables (Table 7.77) shows that some of the correlations were positive, some were negative, and they were mostly weak. Some of these relationships were found to be statistically significant. A moderate, negative and significant correlation was found between maximum canopy diameter and land use (rho = -0.412; p = 0.001). A positive and significant correlation was found between conflict (rho = 0.360; p = 0.001) and land cover (rho = 0.162; p = 0.008). A weak, negative but significant correlation was found between human influence (rho = -0.174; p = 0.004) and maximum canopy diameter. A negative and non-significant relationship was found between maximum canopy diameter and pests and diseases (rho = -0.019; p = 0.759) and maintenance needs (rho = -0.052; p = 0.398).

The Spearman's rank correlation coefficient for stem diameter at first leaf and land use, land cover and external factor variables (Table 7.77) indicates that most of the correlations were statistically significant. A moderate, positive and significant correlation was found between stem diameter at first leaf and conflict (rho = 0.343; p = 0.001). A weak, negative and significant relationship was found between stem diameter at first leaf and land use (rho = -0.251; p = 0.000) and human influence (rho = -0.163; p = 0.008). A very weak, negative and significant correlation was found between stem diameter at first leaf and pests and diseases (rho = -0.128; p = 0.037). A positive but non-significant relationship was found between stem diameter at first leaf and maintenance needs (rho = -0.104; p = 0.091). A positive and non-significant correlation was found between stem diameter at first leaf and land cover (rho = 0.042; p = 0.495).

The Spearman's rank correlation coefficient for volume and land use, land cover and external factor variables is presented in Table 7.77. Some of these correlations were found to be statistically significant. A moderate, positive and significant correlation was found between volume and conflict (rho = 0.384; p = 0.001) and a moderate, negative and significant correlation was found between volume and land use (rho = -0.395; p = 0.001). A very weak, positive and significant correlation was found between volume and land cover (rho = 0.150; p = 0.014) and a very weak, negative and significant correlation was found between volume and human influence (rho = -0.137; p = 0.025). Pests and diseases (rho = -0.018; p = 0.773) and maintenance needs (rho = -0.021; p = 0.733) showed a negative but non-significant relationship with volume.

7.5.4 Impact of land use, land cover and external factors on *Searsia lancea*

7.5.4.1 Frequencies of the VolCalc parameters

Frequency distributions were used to describe the VolCalc parameters. There were only 287 of the *S. lancea* trees (n = 465) in the study with VolCalc data.

The VolCalc parameter frequency distribution results (Table 7.78) indicate that *S. lancea* trees with height ranges of 2.5 – 2.99 m and 3.0 – 3.49 m had the highest frequency (25.1%; n = 72) and those with a height range of 5.5 – 5.99 m had the lowest (0.3%; n = 1). The trees with a height of maximum canopy cover range of 2.0 – 2.249 m had the highest frequency (20.2%; n = 58) and those with ranges of 0.0 - 0.249 m and 4.5 – 4.99 m had the lowest (0.3%; n = 1). The trees with a height at first leaf range of 1.0 – 1.249 m had the highest frequency (20.9%; n = 60) and those with a range of 1.75 – 1.999 m had the lowest (1.4%; n = 4). The trees with a maximum canopy diameter range of 2.0 – 2.49 m had the highest frequency (25.1%; n = 72) and those with a range of 0.0 – 0.49 m had the lowest (0.3%; n = 1). The trees with a stem diameter at first leaf range of 0.050 - 0.099 m had the highest frequency (32.1%; n = 92) and those with a range of 0.450 - 0.499 m had the lowest (0.3%; n = 1). Most of the trees (40.1%; n = 115) were in the volume range of 0.0 – 4.99 m^3 and those with the lowest frequency (0.3%; n = 1) were in three ranges of 30.0 – 34.99 m, 35.0 – 39.99 m and 45.0 – 49.99 m.

Table 7.78: VolCalc parameter frequency distribution results for Searsia lancea

***Searsia lancea* (n = 287)**						
Range	**Tree height (m)**	**Height max canopy diameter (m)**	**Height at first leaf (m)**	**Max canopy diameter (m)**	**Stem diameter at first leaf (m)**	**Volume (m^3)**
1	13	0	11	0	4	115
2	40	0	22	1	92	94
3	72	1	33	10	90	42
4	72	6	75	43	46	17
5	57	8	60	72	23	10
6	22	24	53	55	13	4
7	8	44	29	47	5	1
8	2	57	4	29	5	1
9	1	58		19	6	0
10		24		7	1	2
11		32		2	2	1
12		23		2		
13		5				
14		1				
15		2				
16		1				

The highest two frequency results are highlighted in green and the lowest are highlighted in orange (Table 7.78). From this visual presentation, it can be deduced that except for height of maximum canopy diameter and volume, the frequency distribution of the number of trees for the ranges of the other VolCalc parameters is similar. The frequency distribution is low across the low ranges and very high ranges - highlighted in orange in Table 7.78. The frequency distribution of the number of trees for the height of maximum canopy diameter is in the 8th and 9th ranges. The frequency distribution of the number of trees for the other parameters is the highest between the 2nd and 6th ranges and the frequency distribution of the volume parameter is the highest in the lowest ranks. The frequency distribution ranks decrease as the height at first leaf and volume ranges increase and the lowest ranks are found in the highest ranges. This indicates that most of the trees were small to medium in size. The orange ranges highlight that there were small numbers of trees that were either very small or large.

Table 7.79: Frequency distribution of Searsia lancea *across land use, land cover and external factors*

***Searsia lancea* (n = 287)**						
Range	**Land use**	**Land cover**	**Pests and diseases**	**Maintenance needs**	**Conflict**	**Human influence**
1	76	104	263	158	276	0
2	0	67	24	0	0	0
3	0	25		0	0	0
4	33	34		34	0	0
5	6	2		5	11	0
6	0	20		4		1
7	0	0		0		166
8	59	0		45		37
9	20	0		1		20
10	13	0		10		4
11	0	0		2		14
12	0	0		4		0
13	0	0		15		0
14	0	0		2		0
15	0	0		4		0
16	0	20		1		40
17	0	0		2		0
18	20	0				5
19	0	0				
20	0	0				
21	20	0				
22	0	0				
23	40	15				

The frequency distribution of land use, land cover and external factors (Table 7.79) indicates that the highest frequency distribution of the *S. lancea* trees was in the "formal residential" (26.5%; n = 76) land use category, in the "maintained grass" (36.2%; n = 104) land cover category, did not have any pests and diseases (91.6%; n = 263), did not require any maintenance (55.1%; n = 158), did not present any conflict (96.2%; n = 276) and was in the "maintained" (57.8%; n = 166) human influence category.

7.5.4.2 Relationships/correlations

The relationships or correlations between land use, land cover and external factors and each of the VolCalc variables for *S. lancea* tree species were analysed to determine the impact of land use, land cover and external factors on the VolCalc growth parameters of the species.

The Spearman's rank correlation coefficient for tree height and land use, land cover and external factor variables is shown in Table 7.80 and indicates that most of the correlations were found to be statistically not significant. Some relationships were found to be statistically significant. A weak, positive and significant correlation was found between tree height and land cover (rho = 0.190; p = 0.001) and a very weak, negative and significant correlation was found between tree height and maintenance needs (rho = -0.125; p = 0.034). Pests and diseases (rho = 0.038; p = 0.522) showed a very weak, positive and non-significant correlation with tree height, as did land use (rho = 0.034; p = 0.569) and conflict (rho = 0.005; p = 0.938). A negative, very weak and non-significant relationship was found between tree height and human influence (rho = -0.017; p = 0.781).

The Spearman's rank correlation coefficient for height of maximum canopy diameter and land use, land cover and external factor variables (Table 7.80) shows that most of the correlations were positive. However, some of these relationships were found to be statistically significant even though very weak and weak. A weak, positive and significant correlation was found between height of maximum canopy diameter and land cover (rho = -0.219; p = 0.001) and a very weak, positive and significant correlation was found between height of maximum canopy diameter and human influence (rho = 0.118; p = 0.046). A positive but non-significant correlation was found between height of maximum canopy diameter and land use (rho = 0.067; p = 0.104), "pests and diseases (rho = 0.021; p = 0.723) and conflict (rho = 0.020; p = 0.046). A negative and non-significant relationship was found between height of maximum canopy diameter and maintenance needs (rho = -0.088; p = 0.136).

Table 7.80: Spearman's rank correlation coefficient for VolCalc parameters and tree height and land use, land cover and external factor variables for Searsia lancea

Searsia lancea				
VolCalc parameters	**Variables**	**N**	**Spearman's rank correlation (rho)**	**Probability**
Tree height (m)	Land use	287	0.034	p = 0.569
	Land cover	287	0.190**	p = 0.001
	Pests and diseases	287	0.038	p = 0.522
	Maintenance needs	287	-0.125*	p = 0.034
	Conflict	287	0.005	p = 0.938
	Human influence	287	-0.017	p = 0.781
Height of maximum canopy diameter (m)	Land use	287	0.096	p = 0.104
	Land cover	287	0 .219**	p = 0.001
	Pests and diseases	287	0.021	p = 0.723
	Maintenance needs	287	-0.088	p = 0.136
	Conflict	287	0.020	p = 0.741
	Human influence	287	0 .118*	p = 0.046
Height at first leaf (m)	Land use	287	0.253**	p = 0.001
	Land cover	287	0.265**	p = 0.001
	Pests and diseases	287	-0.053	p = 0.370
	Maintenance needs	287	-0.102	p = 0.083
	Conflict	287	0.022	p = 0.711
	Human influence	287	0.097	p = 0.101
Maximum canopy diameter (m)	Land use	287	-0.188**	p = 0.001
	Land cover	287	0.080	p = 0.177
	Pests and diseases	287	0.142*	p = 0.016
	Maintenance needs	287	-0.112	p = 0.057
	Conflict	287	0.094	p = 0.111
	Human influence	287	-0.183**	p = 0.002
Stem diameter at first leaf (m)	Land use	287	-0.133*	p = 0.024
	Land cover	287	0.178**	p = 0.002
	Pests and diseases	287	0.087	p = 0.139
	Maintenance needs	287	-0.138*	p = 0.019
	Conflict	287	0.133*	p = 0.024
	Human influence	287	-0.193**	p = 0.001
Volume (m^3)	Land use	287	-0.179**	p = 0.002
	Land cover	287	0.113	p = 0.055
	Pests and diseases	287	0.084	p = 0.155
	Maintenance needs	287	-0.093	p = 0.116
	Conflict	287	0.044	p = 0.460
	Human influence	287	-0.154**	p = 0.009

*N = number of trees in sample; rho value with ** indicate significance at 0.001 and * at 0.01*

The Spearman's rank correlation coefficient for height at first leaf and land use, land cover and external factor variables (Table 7.80) indicates that some of the correlations were positive and some were statistically significant. A weak and significant correlation was found between height at first leaf and land use (rho = 0.253; p = 0.001) and land cover (rho = 0.265; p = 0.001). Human influence (rho = 0.097; p = 0.101) and conflict (rho = 0.022 p = 0.711) showed a positive but non-significant correlation with height at first leaf. Maintenance needs (rho = -0.102; p = 0.083) and pests and diseases (rho = -0.053; p = 0.370) showed a negative but non-significant correlation with height at first leaf.

The Spearman's rank correlation coefficient for maximum canopy diameter and land use, land cover and external factor variables (Table 7.80) indicates that some of the correlations were statistically significant even though the correlations were weak. A moderate, negative and significant correlation was found between maximum canopy diameter and land use (rho = -0.188; p = 0.001) and human influence (rho = -0.183; p = 0.002). A positive, very weak and significant correlation was found between maximum canopy diameter and pests and diseases (rho = -0.142; p = 0.016). A positive but non-significant relationship was found between maximum canopy diameter and conflict (rho = 0.094; p = 0.111) and land cover (rho = 0.080; p = 0.177). A negative and non-significant relationship was found between maximum canopy diameter and maintenance needs (rho = -0.112; p = 0.057).

The Spearman's rank correlation coefficient for stem diameter at first leaf and land use, land cover and external factor variables indicates that some of the correlations were positive and some were negative (Table 7.80). Most of these relationships were found to be statistically significant. A weak, negative and significant correlation was found between stem diameter at first leaf and human influence (rho = -0.193; p = 0.001). A very weak, positive and significant correlation was found between stem diameter at first leaf and land cover (rho = 0.178; p = 0.002). A very weak, negative and significant relationship was found between stem diameter at first leaf and maintenance needs (rho = -0.138; p = 0.019) and land use (rho = -0.133; p = 0.024). A very weak, positive and significant relationship was found between stem diameter at first leaf and conflict (rho = 0.133; p = 0.024). Pests and diseases (rho = 0.087; p = 0.139) showed a positive but non-significant relationship with stem diameter at first leaf.

The Spearman's rank correlation coefficient for volume and land use, land cover and external factor variables (Table 7.80) shows that most of these correlations were not statistically significant; however, two relationships were negative and statistically significant. A weak, negative and significant correlation was found between volume and the land use (rho = -0.179; p = 0.002) and human influence (rho = -0.154; p = 0.009). There was no significant relationship between volume and land cover (rho = 0.0113; p = 0.055), pests and diseases (rho = -0.084; p = 0.155), maintenance needs (rho = -0.093; p = 0.116) and conflict (rho = 0.044; p = 0.460).

7.5.5 Summary of the impact of land use, land cover and external factors and VolCalc data

7.5.5.1 Celtis africana

There is a significant relationship between land use, land cover and external factors in relation to the VolCalc growth parameters, but the relationships are weak and for some of the parameters, there is no relationship. The parameters with the most significant relationships for *C. africana* are as follows: tree height and land use (-0.294; p = 0.001), height of maximum canopy diameter and maintenance needs (-0.228; p = 0.001), height at first leaf and maintenance needs (-0.232; p = 0.001), maximum canopy diameter and land use (-0.373; p = 0.001), stem diameter at first leaf and land use (-0.436; p = 0.001) and volume and land use (-0.436; p = 0.001). The variables that mostly affected the significant relationships are maintenance needs (which affected all of the VolCalc growth parameters), land use, pests and diseases and human influences (which affected five of the growth parameters), land cover (which affected four of the growth parameters) and conflict (which affected only three of the parameters).

7.5.5.2 Combretum erythrophyllum

There is a significant relationship between land use, land cover and external factors in relation to the VolCalc growth parameters, but the relationships are weak. The parameters with the most significant relationships for *C. erythrophyllum* are as follows: tree height and conflict (0.229; p = 0.001), height of maximum canopy diameter and conflict (0.188; p = 0.001), height at first leaf and both land use and maintenance needs (0.197; p = 0.001), maximum canopy diameter and conflict (0.242; p = 0.001), stem diameter at first leaf and maintenance needs (-0.166; p = 0.001) and volume and conflict (0.250; p = 0.001).

7.5.5.3 Olea europaea subsp. *africana*

There is a significant relationship between land use, land cover and external factors in relation to the VolCalc growth parameters, but the relationships are weak and for some of the parameters, there is no relationship. The parameters with the most significant relationships for *O. europaea* subsp. *africana* are as follows: tree height and conflict (0.238; p = 0.001), height of maximum canopy diameter and human influence (0.180; p = 0.003), height at first leaf and land cover (-0.327; p = 0.001), maximum canopy diameter and land use (-0.412; p = 0.001), stem diameter at first leaf and conflict (0.343; p = 0.001) and volume and land use (-0.395; p = 0.001).

7.5.5.4 Searsia lancea

There is a significant relationship between land use, land cover and external factors in relation to the VolCalc growth parameters, but the relationships are weak and for some of the parameters, there is no relationship. The parameters with the most significant relationships for *S. lancea* are as follows: tree height and land cover (0.190; p = 0.001), height of maximum canopy diameter and land cover (0.219; p = 0.000), height at first leaf and land cover (0.265; p = 0.001), maximum canopy diameter and land use (-0.188; p = 0.000), stem diameter at first leaf and human influence (-0.193; p = 0.001) and volume and land use (-0.179; p = 0.001).

7.6 Discussion

7.6.1 Distribution of the trees

The distribution of the trees in the study reveals that most of the trees were found on sidewalks and medians in streets of formal residential land use areas (69%) or in parks (31%). International studies on land use focus mainly on determining potential available space for tree planting per land use category to improve the canopy cover of the forest (Nowak et al., 1996; McPherson et al., 2011). Nowak et al. (1996), Dwyer et al. (2000), McPherson et al. (2011) and Mincey, Schmitt-Harsh, & Thurau (2013) confirm that park and residential land uses typically have the highest percentage tree cover. The results of this study are in accordance with international results, indicating that park and residential land use areas are preferred land uses to plant trees. When the trees mature, these land use areas will have the highest percentage tree cover in urban areas (Nowak et al., 1996; Dwyer et al., 2000; McPherson et al., 2011; Mincey et al., 2013). International studies focus on the impact of land use on tree mortality and survival and state that formal residential and park land use areas have a positive impact on the survival of immature trees (Nowak et al., 2004; Lu et al. 2010).

The trees in the study were found mostly in the “maintained grass” (52%), “bare soil” (14%), “unmaintained grass” (14%) and “paving” (6%) land cover categories. The trees did not need maintenance (48%) and 48% required a form of pruning combination. 85% of the trees were not in any conflict with infrastructure but due to their young age they may be in conflict in future when reaching maturity if they are not controlled by pruning. Trees were found mostly in “maintained lawn” (55%) where the surrounding lawn was regularly mowed and the flowerbeds maintained, but also in “unmaintained lawn” (18%) and “pedestrian traffic” (17%). 84% of the trees did not have any pests and diseases. International studies focussing on the distribution of trees in tree planting programmes such as this including reference to land use, land cover, maintenance requirements, conflict with infrastructure, could not be found.

7.6.2 Tree growth in regions

The differences in tree growth could not be attributed to regions. The differences in the circumferences of the trees per region produced conflicting results as the youngest trees were not always the smallest trees, and the oldest trees were seldom the largest trees. There was no proof that trees grew better or worse in a particular region compared to another region. The planting stock may have been varied resulting in inconsistency in the results

7.6.3 Distribution of "missing" trees

The results of the distribution of land use and land cover for the missing trees correlate with international studies in that land use affected the survival of newly planted and young trees and that vacant land had the lowest rates of street tree survival (Nowak et al., 2004; Lu et al., 2010). Therefore, planting trees in vacant land should be avoided. This study also identified a connection between missing trees and the land use categories of informal residential areas and vacant land, and the land cover categories of unmaintained grass and bare soil. Vacant land and informal residential land use areas are not maintained by JCPZ, resulting in unmaintained land cover areas. Due to the lack of maintenance, there is often no vegetative covering, causing bare soil. Missing trees were also prevalent in parks, formal residential and maintained open spaces in maintained lawn and bare soil. Apart from being maintained, these areas traditionally have high levels of human activity, leading to the assumption that these trees may be affected by vandalism when planted in maintained areas. International data suggests that human activities near young trees do affect the survival of these trees (Nowak et al., 2004; Lu et al., 2010; Roman et al., 2014a). Roman et al. (2014b) conclude that stable home ownership, such as is found in formal residential land use areas in this study, together with proper tree maintenance are important variables for tree survival during the establishment phase of a tree planting programme.

7.6.4 Impact of land use, land cover and external factors on circumference of trees

The formal residential and park land use areas had a positive influence on the growth of the trees. Trees growing in these land uses had wider mean CGL measurements than the trees in the other land uses even though they were not the oldest trees. This indicates that they are bigger and grow better, which could be due to better maintenance and protection provided by these land uses, as observed during the study. Conventionally, formal residential and park land uses are maintained compared to informal residential areas, industrial and commercial land uses. International studies focus on the impact of land use on tree mortality and survival and state that formal residential and park land use areas have a positive influence on the survival of young trees (Nowak et al., 2004; Lu et al. 2010). Nowak et al. (2004) also found that tree mortality is negatively affected by transportation, commercial and industrial land uses. The results of this study are consistent with the findings of Nowak et al. (2004) and Lu et al. (2010).

Maintained grass, bare soil and paving land cover areas were found to have a positive impact on the growth of trees. Maintained grass land cover refers to a maintained land cover found in parks, residential areas and open maintained spaces and may have provided a green mulch effect positively influencing the growth. Paving land cover (in this instance) was found at the Rea Vaya bus stations where irrigation and other maintenance was also provided. Some of the trees found in the “bare soil” category were planted during the first year of the project and some of them were found in park land uses where the surrounding areas are maintained. A possible relationship between maintenance and land cover may affect the growth of trees. No international studies could be found that describe the impact of land cover on the growth of trees. However, Elmes et al. (2018) found that trees planted in impervious paved areas increase mortality rates. This is in contrast to the results from this study, but it is suggested that the presence of irrigation and maintenance, together with land cover, can be a determining factor.

This study identified that *C. africana* and *S. lancea* required the least maintenance and *O. europaea subsp. africana* required the most, followed by *C. erythrophyllum*. More than half of the *O. europaea subsp. africana* and *C. erythrophyllum* trees required some form of pruning and most of the pruning needs were due to coppice growth. In a large percentage of these trees, the coppice growth had never been pruned. Most of the maintenance requirements for *C. africana* trees were structural pruning and the *S. lancea* trees were growing skew and had to be straightened. Even though most of the trees were found in maintained land use areas, the absence of tree maintenance was evident, indicating the need for planned maintenance of the project. Vogt, Watkins et al. (2015) state that maintenance is important to ensure the success of tree planting projects and Nowak et al. (1990) and Nowak et al. (2002) indicate that pruning is an important part of the maintenance of young trees, is essential for successful tree establishment and can reduce the pruning requirement of mature trees. According to international studies, maintenance practices such as watering (Lewis & Boulahanis, 2008; Ferrini & Fini, 2011), pruning (Kuhns & Reiter, 2007; Badrulhisham & Othman, 2016) and wound treatment of bark or stem damage to prevent pest and disease infestation (Dujesiefken et al., 2005) contribute to successful tree growth (Ferrini & Fini, 2011; Vogt, Hauer & Fischer, 2015). The results of this study are in line with the conclusions of these international studies. The lack of pruning identified in all the species in all the regions was highlighted and requires attention. Dedicated funding is required to plan and execute formative and corrective pruning for all the species. International studies have highlighted the importance of funding to ensure successful tree planting projects (Thomas et al, 2004; Young, 2011) and improving tree condition and survival (Pauleit et al., 2002). The findings in this current study provide a future research opportunity to ascertain the reasons for the lack of maintenance and find opportunities to implement sustainable maintenance programmes of tree projects.

Most (84%) of the trees in this study did not have any pests and diseases. All the trees in this study are indigenous, which confirms the advantages of planting indigenous trees in projects like these. Very few of the *C. africana, C. erythrophyllum* and *S. lancea* trees had any pests and diseases, indicating that these species should be the species of choice in future tree planting projects. Approximately 50% of the *O. europaea* subsp. *africana* trees were infested with pests and diseases and the infested trees had a smaller mean CGL than the trees that did not have any pests and diseases. Therefore, the presence of pests and diseases on *O. europaea subsp. africana* negatively impacted their growth. This species should be treated with care in future tree planting in the city and attention needs to be given to pest management of the species. Clark and Kjelgren (1989) advocate the implementation of a pest and disease management programme as crucial to the long-term success of urban tree planting, highlighting the importance of the development and implementation of such a programme. At the same time, a scouting programme should be implemented to detect evidence of the polyphagous shot hole borer and the fungus *Fusarium euwallaceae*. Laćan and McBride (2008) state that a pest management programme can potentially limit pest and disease outbreaks but conclude that it will only slow down the catastrophic results of aggressive pests such as the polyphagous shot hole borer.

The categories of human influence impacting the trees were “unmaintained lawn”, “maintained lawn” and “pedestrian traffic”. Trees with the widest mean CGL measurements were found in these categories, even though they were not the oldest trees in the study. However, trees with the smallest mean CGL were also found in the “unmaintained lawn” and the “maintained lawn” categories and were the trees with the lowest mean ages of the youngest trees. The “maintained lawn” and “unmaintained lawn” categories are associated with “maintained grass” and “unmaintained grass”, respectively, in the maintenance requirement categories, which reinforces the importance of maintenance. Contrary to the findings of Lu et al. (2010), who caution that the presence of pedestrian traffic may negatively impact tree growth, the results of this study show that trees with wide mean circumferences were not negatively impacted by pedestrian traffic.

Only 15% of the trees in this study were found in conflict areas and the only categories of conflict impacting the trees were “overhead structures” and “road”. Where large trees of substantial height are planted directly under and in very close proximity to overhead structures such as electrical conductors, the trees will interfere with the overhead structures. This is currently not a major concern as these trees are not mature and have not yet reached their maximum height, but it may become a threat in future. Planting trees under any overhead structures should be attempted with caution (Lewin, Steele-Davies, Rowland, Catterson, Johnstone & Walton, 2013). Kadir and Othman (2012) point out that when mature, tall growing trees are found under or near overhead utility lines, conflict is inevitable. Where trees were found in the “road” conflict category, they were planted too close to the verge of the road and their roots damaged the tar surface. This condition will increase as the trees mature. Randrup, McPherson and Costello (2001) confirm that large tree species will obviously create conflict with sidewalks or kerbs of roads if planted less than 2 to 3 m from the edge of the road. In some instances, in this study trees were planted in locations closer than 2 m from kerbs or sidewalks and may in future present conflict.

A literature search revealed no international studies on the impact of land use, land cover, maintenance requirements, pest and disease presence, human influence and conflict on the growth of *C. africana, C. erythrophyllum, S. lancea* and *O. europaea* subsp*. africana* in an urban environment. This is new information produced by this study.

7.6.5 Impact of land use, land cover and external factors in relation to the VolCalc variables

The impact of land use, land cover and external factors on the growth parameters (referred to as growth) of the trees of this study is statistically significant. The variables that mostly affected this significant relationship were land use, land cover and maintenance needs. The variables that affected the relationships to a lesser extent were human influence, conflict and pests and diseases. It is noted that just because there are significant differences, it does not equate to practical significance or importance and does not meaningfully explain the observed patterns.

All the VolCalc variables except for conflict significantly impacted the growth of *C. africana* Maintenance needs and land use impacted more of the variables, although pests and diseases and human influences also contributed. All the variables significantly impacted the growth of *C. erythrophyllum* but maintenance needs and conflict impacted the growth to a greater extent, and land use and land cover to a lesser extent. The variables that significantly impacted the growth of *O. europaea subsp. africana* were land use, land cover, human influence, pests and diseases, conflict and maintenance needs. Not all the variables impacted all the growth parameters. However, the absence of maintenance needs significantly impacted the growth of *O. europaea subsp. africana* in a positive way. Land cover, land use and human influence are the three variables that significantly impacted the growth of *S. lancea.* Maintenance needs, pests and diseases and conflict had less impact on the growth of *S. lancea* and the absence of pests and diseases and conflict had a positive impact on tree growth.

This study revealed that the trees in formal residential and park land use areas were larger than the trees in other land uses, meaning that they had a statistically significant positive impact on the growth of the trees. The land use of vacant land had a statistically significant negative impact on growth. The land cover variables of maintained grass, unmaintained grass and bare soil impacted tree growth. Maintained grass significantly positively affected tree growth, and unmaintained grass and bare soil significantly negatively impacted tree growth. There is a direct connection between results from the land cover parameter and the results from the maintenance needs parameter as trees that did not need maintenance were on average larger than the trees requiring any form of maintenance, confirming that the growth of trees is negatively affected when they require any maintenance. Where irrigation was provided, the size of trees and the other growth parameters in the land cover areas of maintained grass and paving were significantly positively impacted. The maintenance needs parameter that on its own significantly negatively impacted tree growth is pruning, and if no maintenance was required, this had a positive impact on the growth parameters. The lack of pruning of the trees in the GSTP project has been highlighted throughout this study and it is confirmed that it significantly negatively impacts the growth of trees, emphasising the importance of the development and implementation of planned pruning. The human influence parameter that significantly negatively impacted tree growth is the presence of pedestrian traffic. When pedestrians were found in maintained areas such as parks, tree growth was positively impacted, and when they were found in unmaintained lawn and vacant land, this negatively impacted tree growth. The only species that was significantly negatively impacted by the presence of pests and diseases was *O. europaea* subsp. *africana.* The absence of conflict had a significant positive impact on the growth of the trees and the growth of *C. erythrophyllum* was significantly negatively impacted by overhead structures and trees planted too close to the road and kerb.

This study confirms the observations from previous studies (Nowak et al., 2004; Lu et al., 2010) that trees in maintained areas such as parks and residential areas are more likely to grow better, become mature and have a lower mortality rate than trees planted in unmaintained areas. Roman et al. (2014a) state that planting trees in vacant land should be avoided. The lack of tree maintenance, even in maintained areas, was identified by this study. Ferrini and Fini (2011) insist that planned maintenance is essential for sustainable urban forest management, and as pruning positively impacts tree health and structure, it is seen as one of the most important tree maintenance activities of urban forest management (Badrulhisham & Othman, 2016). Due to the young age of the trees in the study, few trees presented conflict or caused damage to infrastructure, but as a precaution, trees should be planted a safe distance from overhead structures, roads and kerbs (Lewin et al., 2013).

No international research could be found on the relationship between land use, land cover, the type of tree maintenance required, the impact of human influence and conflict or damage caused by infrastructure and the presence of pests and diseases on the growth of the trees in relation to the growth parameters (tree height, height of maximum canopy diameter, height at first leaf, maximum canopy diameter, stem diameter at first leaf and tree volume) of *C. africana, C. erythrophyllum, S. lancea* and *O. europaea* subsp. *africana*. The impact of land use, land cover and external factors on the growth of the four indigenous trees is new information produced by this study.

7.7 Conclusion

The aim of this part of the study was to determine the distribution of the trees in the study across land use, land cover and external factors, to determine if these factors impact the growth of trees and to identify aspects that could impact future planting and maintenance strategies.

This study determined that most of the trees in this study were planted on sidewalks, on medians in streets of formal residential land use areas and in parks. The street trees and the trees in parks were planted mostly in the maintained lawn land cover, confirming previous research claiming that park and residential land uses provide most of the potential planting locations in a city and lead to the highest percentage of tree cover when the trees mature (Nowak et al., 1996; Dwyer et al., 2000; McPherson et al., 2011; Mincey et al., 2013).

This study revealed that formal residential and park land use areas that are maintained have a positive impact on the growth of the trees and a positive connection was identified between land use, land cover and maintenance on the growth of the trees. The maintained grass land cover on its own, together with bare soil and paving land cover areas, also had a positive impact on the growth of trees. Upon investigation it was found that the trees found in bare soil were older and therefore larger than the other trees and some of them were found in park land uses surrounded by maintained lawn. The trees found in the paving land cover were at the Rea Vaya bus stations where irrigation and other maintenance was also provided. All the trees found at the Rea Vaya bus stations were observed to be larger and in better condition than the trees found in streets, on medians and in parks. There may have been separate specifications for these trees, but this could not be confirmed. The impact of maintenance on the growth of trees is emphasised and is integral to the survival and growth of trees. This study confirmed that most of the maintenance needs of the trees in the study were pruning related, affirming the need to establish recommendations for tree maintenance to advise the implementation of preventative and structural pruning of these trees, in guidelines for tree planting in the city. The study also identified that the growth of some of the trees is negatively impacted by the presence of pests and diseases and conflict with overhead structures and roads, indicating the need to include these aspects in the guidelines.

This study identified *C. africana* and *S. lancea* species as the trees impacted the least by aspects such as maintenance requirements, human influences, pests and diseases and conflict and are the best adapted to the urban environment in the CoJ. The coppice growth concern with *C. erythrophyllum* and the pests and disease occurrence with *O. europaea* subsp*. africana* require resolving before these trees will be ideal for use in the CoJ. Where trees are visibly not performing optimally in a specific location, attention is required to either replace the distressed trees with species that will prosper or implement a planned maintenance programme to guide them back to health. The land use and land cover placement of *O. europaea* subsp*. africana* needs consideration to prevent inferior performance. Literature could not be found to collaborate or disprove this statement. Therefore, the identification of *C. africana and S. lancea* as the best adapted trees to the urban environment, the coppice growth concern with *C. erythrophyllum* and the pests and disease occurrence with *O. europaea* subsp*. africana* in the CoJ is new information, which can be used to inform species choice in future tree planting programmes.

Studies determining the impact of land use, land cover and other external factors on the growth of indigenous South African trees, in particular *C. africana, C. erythrophyllum, O. europaea* subsp. *africana* and *S. lancea* species, could not be found. This study is the first to describe the impact of land use, land cover and the different external factors on the growth of indigenous South African trees and identify aspects that could impact future planting strategies. Therefore, the information from this study can be used to guide the placement of future tree plantings for optimum growth possibilities.

This study identified formal residential and park land use areas as the best land use areas to plant trees in a city and revealed that tree planting should be considered carefully in informal residential and vacant land areas. Likewise, it identified that the maintained lawn land cover is the best location to plant trees. Tree planting in unmaintained lawn areas, vacant land, bare soil and paved areas without irrigation should carefully be considered, as this can negatively affect their growth. Trees may be planted in parks in the presence of pedestrians, but where pedestrians are identified in unmaintained areas, the planting of trees should be planned with caution. It is the view of the researcher that trees should not be withheld from areas where they do not grow optimally, but rather that actions should be taken to improve the survival rate of these trees. It was also identified that high levels of human activity may increase vandalism in all land uses. To prevent future conflict of trees and infrastructure, careful planning is needed. Trees should be planted safe distances from roads, kerbs and overhanging structures such as power lines. Implementing a planned maintenance programme with specific reference to pruning and dedicated funding is imperative. These aspects were all identified as influencing future tree planting strategies. Tree planting guidelines with recommendations based on these aspects are presented in the next chapter.

Further research opportunities were identified by this study, determining the reasons for missing trees, the causes of vandalism in the CoJ suggesting prevention measures and the impact of maintenance on the trees planted in specific land cover and land use areas.

CHAPTER 8

TREE PLANTING GUIDELINES

8.1 Introduction

Establishing tree planting programmes that will withstand the test of time is a challenge. Political agendas, pressures from the public supporting these initiatives and limited resources may collectively or individually negatively affect these programmes and their sustainability. These concerns call for guidelines for tree planting programmes to ensure successful implementation and management (McPherson & Young, 2010).

The aim of this chapter was to compile guidelines for new tree planting in the CoJ to prevent a recurrence of the tree survival results of the GSTP should large tree planting projects be implemented in future. The structured literature review identified components for the development of these guidelines, augmented by relevant results from this study. These guidelines are practical recommendations of how the findings from this study can be used by JCPZ to change the practices applied during the GSTP project and are provided as supplementary to the current Tree Management Policy of the CoJ. Where possible, the information in the guidelines is supported by literature or the findings of this study.

8.1.1 Urban forestry management

Urban forests provide quantifiable social, environmental and economic benefits and services to cities (Escobedo, Wagner, Nowak, De la Maza, Rodriguez & Crane, 2008; Conway & Urbani, 2007; McPherson et al., 2005) and have been shown to collectively improve psychological well-being (Chiesura, 2004). Successful urban forestry management relies on a range of comprehensive policies, strategies and management plans (Gudurić et al., 2011) together with a strong implementing organisation and a stable budget (Ottitsch & Krott, 2005). These documents should contain standards, guidelines and recommended best practices guiding a city in the management of the city’s urban forest (Braverman, 2008). Janse and

Konijnendijk (2007) indicate that urban forestry policies and management plans should be grounded on scientific research and Nowak et al. (2010) and Cozad et al. (2005) state that the range of management planning documents depends on measurable objectives and data such as canopy cover percentages, tree species, tree health and possible risks. Salbitano et al. (2016) are of the opinion that assessing the urban forest and completing a tree inventory is the first step in the development of urban forestry management planning, as it is essential to understand the resource before developing plans for the future (Gibbons, 2014). Thereafter, tree planting and maintenance goals, objectives and priorities for the future of the resource can be developed and captured in management planning and implementation documentation (Salbitano et al., 2016).

8.1.2 Urban forestry management in the CoJ

The CoJ does not have a published urban forestry management plan but has a Tree Management Policy, which was in draft format at the time of writing, stating that the urban forest is a valuable asset managed by JCPZ, which is responsible for the planning, planting and care of all the public trees in the city. The policy is linked to relevant legislation and regulatory frameworks of the city and is aligned with the city's growth and development strategy. It provides an approach to the management of the trees, including new tree planting and maintenance within the city, and consists of objectives, guiding principles, risk identification, internal control measures and monitoring (JCPZ, n.d.):

- Objectives of the policy describe the vision for the urban forest and include statements of intent, such as promoting, greening and maximising tree planting and maintenance to secure environmental and social benefits for future generations, encouraging the planting of indigenous and fruit trees, maintaining a set standard for the management of street and park trees, promoting mass tree planting events, ensuring an integrated approach when planning new projects and aiming for a 100% tree survival rate of newly planted trees through aftercare programmes. The JCPZ Tree Management Policy presents a 95% survival rate, showing a plan based on reality.
- Guiding principles broadly describe implementation strategies and JCPZ regulations and conduct regarding tree planting, replacement planting, pruning and the removal of trees.
- Risks identified by JCPZ include the lack of skilled staff, ageing trees in certain suburbs of the city, limited species diversity, incorrect species selection, the lack of maintenance of newly planted trees due to shortages of resources and no disease management programmes in place in the city.
- Internal control measures describe the systems of JCPZ utilised in the management of these trees and actions such as the need to develop tree maintenance standards,

map the trees on a GIS and conduct education programmes to generate awareness of the importance of trees within the urban context.

- Monitoring describes the processes and instruments to be used to evaluate the policy.
- The policy provides information on the accountability, responsibility and coordination of the management of the urban forest within the city.
- The policy promotes tree planting and awareness among residents, securing community involvement and providing training to communities.

8.1.3 Canopy cover assessment and tree inventory

As discussed above, urban forestry planning depends on known canopy cover percentages and tree inventories to enable informed future planning (Gibbons, 2014); the development of guidelines for future tree planting therefore depended on the availability of this data. A complete tree inventory for the CoJ has not been conducted and it is anticipated that due to a lack of resources, it is not planned in the foreseeable future.

8.1.3.1 Canopy cover

The focus of tree planting to improve the canopy cover should be in the poorer, previously disadvantaged regions of the city (Regions D, the southern part of F and G). These regions have been identified as having less (6.7%) canopy cover than the previously advantaged regions (Regions A, B, C, E and the northern parts of F) at 24.2% canopy cover in the city. A visual representation of the tree cover of the CoJ is presented in Figure 1.1 of this thesis (Schäffler & Swilling, 2013).This separation is a legacy of the apartheid regime of the previous government and even though the social realities have shifted, the geographical divisions (Foster, 2009) and contrast remain (Beavon, 2004:10).

8.1.3.2 Tree inventory and risk

This study assessed the trees planted during the GSTP project which culminated in a tree inventory (see Chapter 4) and a risk assessment (see Chapter 7) of the project. The assessment (Chapter 4) indicated that of the 206 267 trees that were planted as part of the project, 89 644 trees were existing in 2018. When the missing trees were taken into consideration, there might only have been 53 038 existing in 2018, indicating a high mortality rate. A range of missing trees were identified, including dead and absent trees as well as dead stumps and trees with coppice only, highlighting the lack of maintenance of these trees. The tree species were identified and revealed the species composition and lack of diversity of the trees in the project. The planting locations of the trees were captured, and the GPS coordinates were used to plot these trees on maps for future reference. The assessment in Chapter 7 revealed the need for pruning the coppice as the most important maintenance activity required, followed by structural pruning, and emphasised that trees grow better when they do not require any maintenance. The need for a pest and disease strategy was identified as certain species were infested. The assessment showed that the presence of pedestrians and the distances from conflicting structures should be considered before planting trees as these may pose risks in future.

The limited survival of the trees, number of missing trees, lack of species diversity and maintenance requirements were identified as risk factors for the success of future tree planting projects. Recommendations for tree maintenance and management is provided later in this chapter. Therefore, it is recommended that JCPZ adopt the improved inventory system provided in Chapter 4 of this thesis.

8.2 Principles for guiding tree planting

Principles to guide tree planting with the aim of reaching the objectives of the Tree Management Policy of JCPZ have been developed based on the specific focus area components of the structured literature review, the findings of this study and the author's understanding of the resource. The canopy cover percentage, tree inventory and risk assessment of the existing trees of the GSTP project collectively provided an understanding of this resource. By interpreting this evidence, principles for tree planting were created and thereafter guidelines for the implementation of these principles.

Guiding principles for tree planting in the CoJ are as follows:

- Improve the canopy cover of the previously disadvantaged regions of the city.
- Maintain and improve the existing canopy cover of trees in the historically wealthy northern suburbs of the city.
- Improved species selection and planting procedures.
- Improved maintenance procedures.
- Aim for a 100% survival rate of new tree planting projects.
- Engage local communities and stakeholders in new tree planting projects to promote tree planting, create awareness and establish involvement.
- Monitor and measure progress to celebrate success.

A description is now provided of the guiding principles and how they relate to the Tree Management Policy of JCPZ with required actions.

8.2.1 Improve the canopy cover of previously disadvantaged regions

One of the outcomes of the JCPZ Tree Management Policy is to create a balance between the previously advantaged and the previously disadvantaged areas in the city. This inequality also includes the unequal distribution in the extent of tree canopy cover between these regions (Schäffler & Swilling, 2013), indicating that tree planting should be focused in previously disadvantaged areas. Therefore, growing the canopy cover in Regions D, F and G is the first principle of these guidelines, which requires a commitment to a percentage increase per annum and the development and implementation of tree planting programmes in these regions. The structured literature review indicates that appropriate planning and management mechanisms are needed to improve canopy cover and manage the urban forest in a sustainable manner (Kirnbauer et al., 2009; Deb et al., 2013; Pincetl et al., 2013). Improving the canopy cover relies on ensuring that the planted trees remain alive and grow to a mature size.

Required actions to improve the canopy cover of previously disadvantaged regions are as follows:

- Set a target to improve the number of trees in these regions by between 5 and 10% per annum to increase the canopy cover over time and balance the tree cover. JCPZ should commit to a percentage.
- Once a percentage improvement has been determined, JCPZ should develop a five-year plan aimed at reaching the target. This plan should include not only time frames, number of trees and locations, but also a list of tree species together with tree size/growth form specifications (total tree height, height of the stem at branching, crown dimensions and diameter or circumference at breast height or 1.37 m from the ground) and the nursery container size (20, 40, 50 or 100 L).
- Establish communication with suppliers regarding the availability of the species as specified to enable them to produce the correct quantity and quality of trees.
- The plan can be used to secure funding from the city or other stakeholders. Securing funding is of the utmost importance as implementation of the plan depends on funding. Without it, the canopy cover of the city and particularly the previously disadvantaged regions of the city will remain the same.

8.2.2 Maintain and improve the percentage canopy cover

Maintaining the existing number of trees in the historically wealthy northern suburbs to preserve the existing tree cover requires attention as a number of trees in previously advantaged areas such as Sandton, Rosebank and Houghton are reaching the end of their productive life and this places the current canopy cover percentage in jeopardy. The Tree

Management Policy states that JCPZ will monitor the health of these trees and replace each of the trees as required. A strategic programme of tree replacement was to be developed in 2014 (JCPZ, n.d.), but no proof of such a strategy could be found.

To maintain the 24.2% canopy cover in the previously advantaged regions of the city, continued survival of these trees is imperative. This relies on improved management practices such as the implementation of suitable maintenance practices (Morani et al., 2011; Roman et al., 2014a; Roman et al., 2015). Mokoena (2020) found that the trees in these areas are all mature, mostly exotic (e.g. *Platanus x acerifolia, Jacaranda mimosifolia* and *Ulmus parvifolia*) and were planted more than 50 years ago. Except for ad hoc structural pruning, no planned maintenance is required. Mokoena (2020) also reports that evidence of the polyphagous shot hole borer (*Euwallacea* sp.) and the fungus *Fusarium euwallaceae* has been detected in these suburbs on an increasing number of trees and mainly on exotic species. Given the impact of the pest on a broad range of tree species in Asia and the USA, including species native to South Africa such as *Erythrina lysistemon* and *Schotia brachypetala* (Paap, et al., 2018), urgent attention is needed to identify the reproductive hosts and compile an action plan to manage this pest. Mokoena (2020) stresses that as of 2020, no pesticide had been registered to control the pest and the infested trees would have to be removed to prevent the spread of the disease.

The following actions are required to maintain and improve the existing canopy cover of the urban forest of the CoJ:

- Develop and implement a maintenance plan for all trees in the city. A maintenance plan is discussed below.
- A tree replacement strategy is required to guide the replacement of trees reaching the end of their productive life.
- A strategy for the management of the polyphagous shot hole borer should be developed and include aspects such as removing infected limbs where partial infection is detected, chipping the wood (2.5 cm or less), followed by solarisation or burning (Greer, Rice & Lynch, 2018). Mokoena (2020) states that the disease is spread through selling the wood as firewood; this is therefore not recommended. Heavily infected trees should be removed and replaced with non-host species (Greer et al., 2018).
- Community involvement should be encouraged, and a framework established. JCPZ should form a working group combining the local authority, interest groups and the local community to identify decision-making processes, communication forums and measurable objectives to guide the actions taken and remain focused on the aim of

the project. This forum should also focus on the acquisition and application of funding (Greer et al., 2018).

8.2.3 Improve survival rate of new tree planting

Aiming for a 100% survival rate (JCPZ, n.d.) of new tree plantings requires a focused approach to tree planting and maintenance in the city. The survival of newly planted trees (Moskell & Allred, 2013) and the continued survival of these trees rely on selecting the best planting locations (Kirnbauer et al., 2009; Lu et al., 2010; Nowak et al., 2004), the ideal species (Allen et al., 2017; Roy et al., 2017; Carmichael & McDonough, 2018), the implementation of rigid planting specifications (Koeser et al., 2014; Roman et al., 2015; Allen et al., 2017) and suitable maintenance practices (Pincetl, 2010; Conway, 2016; Widney et al., 2016), depending on available resources and funding (Dawes et al., 2018; Galenieks, 2017; Kirkpatrick et al., 2013).

Focusing the aim of new tree planting projects on ambitious planting goals is not viable. The target number of trees (n = 200 000) of the GSTP project were planted, but this study has revealed that only 43.46% (n = 89 644) trees survived in 2018 (Chapter 4). If the target had been less optimistic, for example 100 000 trees, and there was a plan to ensure a 95% survival rate, the project could have been more successful. Carmichael and McDonough (2018) caution that planting large numbers of trees should not be the overriding goal of tree planting programmes and contend that the success of these programmes relies on the involvement of the local community in the entire programme. Local authorities are responsible for tree planting projects (Conway & Bang, 2014) and should create opportunities for communities to become involved (Carmichael & McDonough, 2018). A lack of awareness of communities leads to non-participation and thus campaigning and marketing are required (Dawes et al., 2018).

Required actions to improve the survival rate of new tree plantings are the following:

- Identify realistic targets for tree planting aimed at positively improving the canopy cover.
- Tree maintenance and care are essential for the survival of newly established trees (Roman et al., 2014b) and are particularly important during the first five years after planting (Miller & Miller, 1991; Sherman et al., 2016; Elmes et al., 2018) to establish a 100% tree survival rate.
- Tree planting education and awareness programmes utilising all types of media for communication (print, visual and audio media) as well as public education forums, road shows, school programmes and social media (Facebook, Instagram and Twitter) should be created and implemented.

8.2.4 Community involvement

A framework for the involvement of the community should be developed and implemented. This framework should detail the working relationship to ensure that the focus of all the entities is aimed towards the same goal. Involving, engaging and educating local communities and stakeholders in the planning and management of the urban forest have proven to be beneficial for the long-term survival of these trees and to increase tree cover. Community engagement initiatives also assist in improving the governance of the urban forest and reduce resistance of communities to tree planting programmes and usually leads to lower rates of vandalism (Carmichael & McDonough, 2018; Dawes et al., 2018; Elmes et al., 2018).

The following actions are required to develop and implement community engagement:

- A framework for the involvement of the community should be developed and implemented before the next tree planting project commences by utilising existing structured community and stakeholder forums (Friends of the Parks, residents associations, inner city forums, councillor forums and the Johannesburg Urban Forest Alliance).
- Develop and implement community education, information and communication plans to raise awareness and provide education opportunities focusing on the need for and care of newly planted trees as well as the preservation of all trees in the urban forest.
- Community involvement structures should be put in place to provide input in the selection of tree species, the location of trees (Jennings et al., 2016; Carmichael & McDonough, 2018) and tree maintenance (Moskell et al., 2016; Mincey & Vogt 2014).
- Clarifying the responsibilities of the city and the community prior to the initiation of the tree planting project (Sklar & Ames, 1985) is important, as is the implementation of stewardship programmes responsible for tree care and maintenance (Roman et al., 2015; Moskell et al., 2016).

8.2.5 Performance measurement

Performance indicators are required to enable the measurement of progress towards achieving the objectives of the strategy over a period (Kenney et al., 2011). Performance indicators are used to identify shortcomings in the strategy and management of the tree planting programmes, providing information to adapt and improve the strategy (Dwyer et al., 2000). The objectives of the strategy cannot be tested if these objectives are not measured (Cozad et al., 2005). Therefore, a process must be developed to ensure continuing improvement in the management of tree planting in the urban forest, by measuring the implementation of the objectives of the strategy on an annual basis. This process relies on the development of relevant performance indicators and the availability of data and should be linked to the key performance indicators of the CoJ. The process will culminate in a management report which will report on successes, concerns and benefits of the tree planting projects, community involvement and the cost of tree planting and maintenance. This management report must inform the public to ensure continued community engagement, brief all other stakeholders to ensure continued funding and create opportunities for additional funding.

Required actions for performance measurement are as follows:

- Develop measurement criteria for new tree planting aimed at identifying improvement opportunities for new tree planting.
- The results of the measurement process must be used to develop, implement and maintain a continual improvement strategy and actions to re-evaluate the current operating procedures on an annual basis. The improvement strategy must be based on short- (one-year), medium- (five-year) and long-term (ten-year) arboricultural and urban forestry goals and the implementation of strategies and actions to maintain continual improvement of tree planting.
- Progress towards achieving the objectives and the implementation of the recommendations must be monitored and measured (McPherson, 2014; Ko et al., 2015).

The principles are supported by recommendations to provide direction to JCPZ for the implementation of the objectives set out in their Tree Management Policy. Actions, targets and time frames for new tree planting based on the guiding principles are described below as guidelines and recommendations.

8.3 Guidelines and recommendations

Following on the principles discussed above, guidelines with recommendations are derived from this current study and the steps required to implement new tree planting projects in future are explained. This study identified that the success of future tree planting projects depends on selecting locations for tree planting that will contribute to tree survival and growth, selecting tree species that are suited to the environment and the urban conditions, planting trees according to best practice principles and specifications, maintaining these trees for a period of time and having sufficient resources to implement and maintain the project for an extended period of time. Therefore, these steps are:

- Identify locations for tree planting.
- Select tree species.

- Develop tree planting and replacement specifications.
- Develop and implement maintenance plans and specifications.
- Identify resources required to implement the tree planting plan and maintenance operations.

Guidelines are described and recommendations made for each guideline to direct the implementation of these steps.

8.3.1 Identify locations for tree planting

Environmental conditions in urban areas represent challenges for tree survival as increased temperatures and pollution levels negatively affect growing conditions (Pauleit, 2003). Successful tree establishment depends on, among other things, the choice of planting sites or locations (Pauleit, 2003), influenced by selecting trees appropriate to the climate and environmental conditions (Conway, 2015; Martin et al., 2016) and taking the impact of urban factors such as human activities and structural elements into consideration (Scharenbroch et al., 2017).

International research has indicated that land use affects the choice of planting locations and that tree planting in industrial areas, vacant land and open spaces (Kirnbauer et al., 2009; Lu et al., 2010), as well as in transportation and commercial land uses (Nowak et al., 2004) have low survival rates. The same studies have shown that formal residential areas have the best survival rates. This current study has revealed that in terms of the CoJ, the best land uses for tree planting are formal residential and park land use areas as these areas have a positive influence on the growth of the trees (Chapter 7). These results are consistent with the findings of Nowak et al. (2004) and Lu et al. (2010). This study has also revealed that vacant land had the most missing trees, followed by informal residential areas and therefore tree planting in these land uses should be considered carefully.

The best land cover to plant trees identified by this study is maintained lawn land cover. Trees should not be planted in unmaintained lawn areas, on vacant land, bare soil and in paved areas without irrigation as this can negatively affect their growth. However, if these trees are maintained well, these concerns can be overcome. Elmes et al. (2018) report that paving as a land cover negatively affects tree growth; however, this current study has found that where trees are planted in paving (where irrigation is provided), this has a positive influence on the growth of trees. The Tree Management Policy of JCPZ does not refer to taking land use or land cover into consideration when choosing tree planting sites.

Literature indicates that urban conditions and elements such as human conflict, traffic, construction, structures and the socio-economic status of the environment should be taken into consideration when choosing planting locations (Limoges et al., 2018; Elmes et al., 2018; Ko et al., 2015). Lu et al. (2010) report that the presence of pedestrian traffic negatively impacts tree growth; however, the results of this study show that larger trees are not negatively impacted by pedestrian traffic, but juvenile trees are. Trees in conflict with overhead structures (such as power cables), roads and kerbs may impact tree growth. The Tree Management Policy of JCPZ does refer to the regulatory framework of the city prohibiting planting locations close to gas, electricity and telecommunication lines, water supplies and sewerage systems, where it may cause visual and physical obstructions in future or where there is insufficient space (JCPZ, n.d.).

Therefore, the following recommendations are made:

- When identifying locations to plant trees, the first option should be to plant street trees trees in formal residential and park land use areas and to implement rigid maintenance specifications when planting trees in vacant land and informal residential areas.
- With regard to land cover, the prime position would be to plant trees in maintained lawn and not in areas where maintenance is not provided, such as unmaintained lawn areas, bare soil and paved areas without irrigation. *C. africana* trees should rather be planted on sidewalks than on medians, *S. lancea* trees should preferably be planted on medians and *C. erythrophyllum* may be planted on sidewalks or medians as they grow well in both locations. *Olea europaea* subsp*. africana* trees should only be planted in parks as they do not grow well on sidewalks or on medians.
- Based on field observations, it is the perception of the researcher that trees should be located at least 2 m from a road or kerb to prevent conflict. Field observations also reveal that care should be taken when planting trees close to or underneath overhead cables or any other structural element in the urban environment. The plant choice should only include trees that are small enough to prevent conflict.

8.3.2 Select tree species

The structured literature review (Chapter 2) identified the choice of tree species as the most important factor to be considered when new tree planting projects are planned (Allen et al., 2017; Roy et al., 2017; Carmichael & McDonough, 2018). This study revealed limited species diversity in the GSTP project (13 indigenous species were identified). However, four species (*C africana* (30.43%), *C. erythrophyllum* (30.05%), *S. lancea* (15.99%) and *O. europaea* subsp*. africana* (14.23%)) comprised 90.7% of the trees in this project, resulting in the limited species diversity (Chapter 4). The emphasis on planting indigenous trees and the availability of a range of tree species at suppliers contribute to the limited species diversity in an urban forest (Conway & Vander Vecht, 2015).

Therefore, the following recommendations are made:

- Develop a list of preferred trees to not only improve species diversity and tree survival, but also ensure that the best suited species are chosen for each location, climate and micro-climate.
  - This list should declare that indigenous trees are preferred but exotic trees should be planted in locations where the environment, climate and micro-climate do not favour indigenous species (Almas & Conway, 2016) or where they are best suited. The understanding gained through the field observations is that if selected non-invasive exotic species (e.g. *Acer buergerianum, Ulmus parvifolia, Liquidamber styraciflua*) had been included in the planting list, the species diversity would have been improved.
  - Selection should identify trees best suited to urban environments that can tolerate compacted soil conditions, limited root space and air pollution conditions (Clark & Kjelgren, 1989; Abdullah et al., 2018).
  - Trees posing a risk of invasion or on the alien invader list (Conservation of Agricultural Resource Act 43 of 1983) should not be planted and trees identified as host trees for the polyphagous shot hole borer should also not be planted in future. Field observations indicate that methods should be put in place to identify alien invaders on public land and remove and replace them with indigenous or non-invasive exotic species.
  - Selection should also be based on avoiding trees known for causing allergies, shedding of leaves, fruit and flowers or limbs and branches, or that are fire hazards (Kirkpatrick et al., 2013).
- This list must form part of the guidelines and should be made available to tree growers in the province to enable them to have appropriate stock available for planting.
- The development of a tree species list should be based on research conducted in each region of the city to expand the list of known species, also involving the tree nursery (Huddle Park Nursery) of the city.
- This study (Chapter 7) identified *C. africana and S. lancea* as the trees best adapted to the urban environment in the CoJ and should therefore be the first choice for planting in the city. Together with these species, *C. erythrophyllum* was identified as having very few pests and diseases and is therefore also a preferred tree species, but its success is dependent on managing its coppice growth. This study identified that *O. europaea* subsp.

africana was not pest resistant and where found in unmaintained areas, did not perform well. However, where this species was found in maintained areas, it did grow well, indicating that it should ideally be planted in these areas.

8.3.3 Develop tree planting and replacement specifications

Detailed tree planting specifications are crucial for the establishment and survival of newly planted trees and should include information on arboricultural best practices regarding planting techniques and proper handling (Koeser et al., 2014; Roman et al., 2015; Allen et al., 2017). These specifications should be developed prior to the implementation of any tree planting projects and should be enforced for all new tree planting in the city.

It was observed in the field that the trees were not all planted according to the same planting specifications, as different tree pit sizes were observed, the backfill and soil conditions were inconsistent and trees were found at different heights in the planting pit. Indications were that trees received watering for two weeks after planting (Chokoe, 2017).

The following recommendations are made for the development of tree planting specifications, along with descriptions of the correct way to plant a tree to give the tree the best chance of survival, based on arboricultural best practices and the field observations during this study:

- Describe tree pit specification parameters such as the size and shape of the pit.
- Quantify a watering regime directly after planting, for example once per week for the first growing season (Vogt, Hauer & Fischer, 2015).
- Improve the quality of the soil used for backfilling the tree pit by adding organic amendments to positively influence initial establishment as well as the medium-term growth of newly planted trees (Grey et al., 2018).
- Ensure consistent planting depth at the surrounding soil level (Gilman & Grabosky, 2004). Trees should not be planted too deeply, with too much soil covering the root ball.
- Identify the type, size and application of tree support and protection system to provide temporary mechanical support required to keep the newly planted tree upright, otherwise known as tree stakes (Thacker et al., 2018).
- Applying mulch to the surface surrounding the tree stem and of newly planted trees is promoted to maintain soil moisture. However, the type and depth of mulching material should be evaluated to ensure optimum functioning (Gilman & Grabosky, 2004).

This study identified an opportunity for the planting of additional trees to replace the missing trees categorised as “dead”, “absent”, “dead stumps”, “coppice only” or “dead trees with coppice". The Tree Management Policy of JCPZ refers to tree replacement as "blanking" and states that where trees have died, were damaged by vandalism or human activity, or where they have come to the end of their life, they may be replaced. The current study identified that 15.37% of the existing trees in the project were "missing" in 2017, creating an opportunity for the planting of 8 151 trees (Chapter 4) without having to find new locations for them.

Recommendations for the development of tree replacement specifications are as follows:

- Reword the statement in the policy ensuring that all missing trees are identified and replaced.
- Implement annual or bi-annual inspections of all the public-owned trees in the city to identify missing trees.
- When trees have reached the end of their lives, they should be replaced in a planned manner by involving the community, choosing species that have not been identified as host trees for pests and diseases and choosing species that in time will contribute the same quantity of carbon sequestered as the replaced tree.

8.3.4 Develop and implement maintenance plans

The researcher realised during field observations that tree maintenance was not conducted on a regular basis. The survival of newly planted trees (Moskell & Allred, 2013) relies on the implementation of suitable maintenance practices (Pincetl, 2010; Conway, 2016; Widney et al., 2016). Tree maintenance practices involve inter alia watering, mulching and site care, tree staking and removal, pruning as well as pest and disease control (Clark & Kjelgren, 1989; Roman et al., 2015). Watering is seen by some researchers as the most important maintenance practice to ensure tree survival of newly planted trees (Gilman et al., 2014) and pruning is essential to shape urban trees, prevent problematic growth shapes and correct structural damage (Clark & Kjelgren, 1989). Abdullah et al. (2018), Thacker et al. (2018) and Richardson and Shackleton (2014) agree that vandalism and the absence of or incorrect arboricultural practices negatively impact tree health and newly planted trees, causing poor tree conditions and necessitating careful planning and implementation of tree planting programmes.

This study has identified a lack of maintenance of the trees (Chapters 4 and 7). Even in areas where trees were found in maintained lawns, arboricultural maintenance was not done. The most important maintenance activities required were pruning the coppice (39% of the trees in the study), followed by structural pruning (30%) (Chapter 7). A range of other maintenance requirements were identified in this study (Chapter 7), such as removing wires and cable ties placed around tree stems for signage purposes and left on the tree (5%), correcting skew growing trees leaning at an angle of less than 90 degrees due to the breakage or the premature removal of tree stakes (4%) and repairing bark damage where the bark was removed for medicinal use purposes or due to mechanical damage by brush cutters (2%). The remaining 20% comprised trees needing pruning together with some of the other types of maintenance.

The Tree Management Policy of JCPZ stipulates that tree maintenance should be based on sound arboricultural practices and applied uniformly across the city, but further acknowledges that tree maintenance does not receive the same attention as lawn maintenance and that the non-maintenance of newly planted trees poses a risk to tree survival. The policy does identify the need to develop and implement tree maintenance standards for the city and states that all the newly planted trees should be subjected to a maintenance plan to ensure a 100% survival rate. The policy does not provide guidance on the actions and time frames involved in tree maintenance.

Tree maintenance of new trees is important during the first five years after planting (Miller & Miller, 1991; Sherman et al., 2016; Elmes et al., 2018) and therefore a five-year maintenance plan should be developed specifying maintenance practices and time frames. Watering is the most important maintenance practice to ensure tree survival of newly planted trees (Pincetl et al., 2013; Koeser et al., 2014; Mincey et al., 2014) and pruning is essential to shape young trees for city environments (Clark & Kjelgren, 1989).

Destructive pests and diseases introduced from overseas threaten the trees in South Africa, as indigenous species lack effective defence mechanisms in the absence of beneficial biological organisms to assist in minimising pest population outbreaks and the accompanying tree mortality (Gulick, 2014). When the urban forest contains exotic trees, there is an increasing likelihood of pests finding a suitable host to establish themselves (Paap, Burgess & Wingfield, 2017). This study found that only 16% of the trees had any pests or diseases but 50% of the *O. europaea subsp. africana* trees were infested, requiring focused attention on pest management of this species (Chapter 7). A pest and disease strategy is crucial for the long-term success of urban tree planting (Clark & Kjelgren, 1989), as an uncontrolled outbreak can have a potentially devastating impact on the urban forest.

In the USA, urban tree planting projects and maintenance are successfully conducted by creating and involving communities in stewardship programmes, and research has established that community stewardship increases the survival of urban trees (Jack-Scott et al., 2013; Roman et al., 2015; Moskell et al., 2016), validating the need for an investigation into stewardship programmes and tree maintenance as this practice is not yet applied in South Africa. Prior to the implementation of new tree planting, JCPZ should investigate the need for and application and implementation of stewardship programmes to assist in the maintenance of the newly planted trees. This study has identified one incidence (Region A) where evidence of community involvement in maintaining the trees had a positive impact on the growth and condition of the trees (Chapter 7).

Recommendations for the development and implementation of tree maintenance specifications involve the development of a maintenance regime by combining the types of maintenance activities (pruning, watering etc.) with any given frequency (time frames such as monthly or weekly), intensity (e.g. 50L of water per application) and duration (for a period of five years) for newly planted or established trees (Vogt, Hauer & Fischer, 2015). These recommendations are as follows:

- Develop a five-year maintenance plan for newly planted trees after the completed establishment phase or the first growing season with a focus on:
  - watering once a month for at least a six-month period, depending on the rainfall (Gilman, 2004)
  - mulching the area surrounding the tree stem to improve soil moisture (Vogt, Hauer & Fischer, 2015)
  - providing optimum chemical and physical soil properties by annual additions of chemical or organic amendments in the five-year maintenance period (Grey et al., 2018; Vidal-Beaudet et al., 2018; McGrath & Henry, 2016)
  - monitoring tree planting support and protection systems or tree stakes and removing them once no longer required, within one or two years after planting (Thacker et al., 2018)
  - replacing tree stakes if they are no longer functional but required to keep the tree growing in an upright position.
- Conduct a thorough inspection of the condition/health of the trees one year after planting and adapt the maintenance accordingly, as trees should have established by then, requiring less intense maintenance (Koeser et al., 2014).
- Apply the well-known pest and disease strategy known as integrated pest management (IPM) or the new Adaptive Peat Management framework to all newly planted trees. This strategy involves integrating cultural practices, scouting, analysing life cycles and pesticide application strategies to effectively manage any pest populations and can be applied to urban forests with great success (Raupp, Koehler & Davidson, 1992).
  - Scouting has been identified as the most important part of IPM as early detection of pest and disease threats is vital to prevent destructive infestations (Gulick, 2014; Paap et al., 2017). Therefore, scouting programmes to detect evidence of any pests or diseases should be developed and implemented.

- Prior to new tree planting, JCPZ must investigate the implementation of stewardship programmes to assist in the maintenance of the newly planted trees.

8.3.5 Identify resources required to implement tree planting and maintenance operations

Urban forestry programmes in South Africa are governed and funded through the general tax levy as part of the public service provided by local governments. It is reported that the designated budgets are seldom sufficient (Chishaleshale et al., 2015). Similar concerns have been highlighted in Fort Lauderdale, USA (Dawes et al., 2018), Loma Linda and Redlands, California (Galenieks, 2017) and major cities in the USA (New York, Los Angeles, Houston, Baltimore, Seattle, Denver, Albuquerque, Sacramento and Salt Lake County) (Young, 2011). Booth (2006) asserts that well-developed and well-coordinated urban forestry planning improves the ability of city council officials to motivate and compete for financial and human resources. The need to present local government political leaders with proof of the benefits of sustainable tree planting is therefore critical to earn their support for the approval of sufficient funding (Chishaleshale et al., 2015).

As city council officials have indicated that insufficient funds and human resources are their main challenge in implementing urban greening programmes (Chishaleshale et al., 2015), of which tree planting is one component, creative alternative funding strategies are essential for the implementation of new projects. Funding opportunities may include local government capital improvement funds and, if managed well and their longevity and ecological services value to infrastructure and communities can be proven, the funding will be justified (Gulick, 2014). Whitehead, Hansmann, Lohrberg, Živojinović, Bernasconi and Jones (2017) suggest that creating partnerships with two or more stakeholders may present cost-effective solutions for tree planting and maintenance through their ability to leverage funding, additional resources and support.

Arabomen, Chirwa and Babalola (2019) indicated that residents from Benin City, Nigeria were willing to contribute towards the conservation of trees in the city. The willingness-to pay was influenced by income and education and demonstrated a positive perception of urban trees in the city. Striving towards a similar positive perception of urban trees in the City of Johannesburg could lead to a similar willingness-to pay for the conservation and maintenance of the trees in the urban forest.

The following recommendations are made for the identification of resources:

- Utilise the monetary value of the GSTP project developed by this study (Chapter 6) to present local government political leaders with proof of the value of this asset. The difference in the value of this project if all the trees were alive compared to the value of the estimated existing trees should be indicative of the need to provide funding as well as aftercare.

- Initiate further research studies to provide local government political leaders with proof of additional benefits of sustainable tree planting, improving both the environment and communities, aiming to earn their support for the approval of sufficient funding.
- Initiate the development of fundraising projects involving international and local non-profit organisations, donors and tree planting agencies.
- Develop private sector partnerships that might fund planting to meet private sector goals in terms of social responsibility and two to offset their own carbon emissions.
- Initiate a research study to determine the willingness-to pay for the conservation and maintenance of the trees in the City of Johannesburg as a funding opportunity (Arabomen et al., 2019).

8.4 Discussion

Assessing the urban forest and developing a tree inventory is required for the development of urban forestry management planning, as sound management plans depend on measurable objectives, which in turn rely on available data on current canopy cover percentages, tree species distribution, tree health and possible risks (Cozad et al., 2005; Salbitano et al., 2016; Gibbons, 2014). The assessment in this study of the trees planted during the GSTP project provided a tree inventory of the species planted and determined distribution of the species, the maintenance requirements and possible risks. This inventory, together with the canopy cover assessment by Schäffler et al. (2013), provided an understanding of this resource and formed the foundation for the tree planting guidelines.

The principles of the tree planting guidelines were developed and linked to the Tree Management Policy of JCPZ and include improving the canopy cover by 10% per annum in the previously disadvantaged regions in the city, maintaining the quantity of trees and the canopy cover percentage in the historically wealthy northern suburbs, aiming for an improved survival rate of new tree planting projects, developing local community engagement structures for involving communities in the planning and management of new tree planting projects and developing performance measurement indicators.

Based on the survival rate (43.46%) of the GSTP project revealed by this study, aiming for a 95% survival rate of new tree planting projects might not be viable as it would require a substantive improvement. Aiming for a 75% survival rate might not look as impressive as a policy statement, but will still require the current survival rate to be improved by 31.54%, highlighting the need to improve the current tree planting and maintenance practices. However, aiming for a survival rate of less than 100% implies a plan to fail. Therefore, the aim should be to have a 100% survival rate of new tree planting projects and by applying correct tree selection procedures, selecting optimum planting locations, abiding by best practice planting and maintenance specifications, this should be achievable.

Guidelines with recommendations were suggested and the steps required to implement new tree planting projects according to the acknowledged principles were explained. The first step was identifying locations for tree planting based on placing trees in a land use type and providing land cover surrounding the tree to afford the trees the best opportunity for growth and survival. Urban conditions and elements such as pedestrians, roads, kerbs and overhead structures should be taken into consideration when choosing planting locations. The second step is to select the best tree species. This was identified in the structured literature review as the most important factor to be considered in planning new tree planting projects. Species diversity was described, and the best adapted species were identified by this study as ideal for the city. The third step entails developing and implementing tree planting and replacement specifications based on arboricultural best practices and describing planting techniques, proper handling and transplanting. Step 4 is the development of maintenance specifications and plans, as the continued survival of trees in urban environments relies on the implementation of suitable maintenance practices. The lack of maintenance was highlighted in this study, establishing the need for focused long-term maintenance based on best practice principles. The last step is to identify dedicated resources (human resources, equipment and funding) imperative for the success of new tree planting projects.

Priorities for the implementation of tree planting guidelines were determined based on the structured literature review and the findings of this study. Firstly, the importance of engaging the community is essential for the successful planning, implementation and maintenance of tree planting programmes. A lack of awareness by communities leads to non-participation and thus focused campaigning and marketing are required. Community involvement includes input in the selection of the tree species and the location of the trees, care and maintenance. The success of urban forestry programmes relies on a clarification of the responsibilities of all the parties involved prior to the initiation of the tree planting project and the implementation of stewardship programmes responsible for tree care and maintenance.

Tree maintenance was identified as a priority in the structured literature review and by this study. A lack of evidence of routine or specialised maintenance was observed during the study. Implementing a maintenance programme during the establishment phase of any tree planting project is crucial for the survival and growth of newly planted trees. Maintenance is mentioned in the Tree Management Policy of the JCPZ as (a) an outcome, stating that tree maintenance will proactively be managed, (b) as a policy objective, stating that maintenance will be integrated in a city-wide approach, and (c) as an implementation strategy, stating that pruning will be conducted. Tree survival is particularly important during the establishment phase, as high survival rates of newly planted trees determine the effectiveness and success of tree planting programmes. Therefore, the development of a detailed tree maintenance plan accepted by all stakeholders with input from the community and backed by sufficient funding and resources from the local government is imperative to reach the targeted 100% survival rate of new tree planting. Guthrie and Shackleton (2006) reveal that there are relatively few policies that deal with urban tree planting and maintenance in South Arica. Where such policies exist, they rarely refer to specifications for implementation and maintenance.

The removal or pruning of coppice growth is the most important maintenance requirement of the trees in the study. The JCPZ Tree Management Policy does not refer to coppice growth, and coppice growth as a concern regarding urban trees could not be verified by literature. This study revealed that most of the trees in the study required some form of maintenance, of which approximately a third required pruning of coppice growth to ensure the correct upright growth structure of an urban street or park tree. A further 8% of the trees in the study were classified as “missing” as they were found with coppice growth only. These trees cannot be repaired by any form of pruning as the coppice growth has replaced the main stem of the tree, leaving a shrub-like growth form. The only remedy is to replace these trees. This highlights the urgency to prune the coppice to prevent these trees from becoming part of the missing tree data in future.

The second most important maintenance requirement identified by this study is structural pruning. 30% of the trees needing maintenance in this study required correcting of the shape. Lewis and Boulahanis (2008) list pruning as one of the challenges of maintenance of the urban forest, and Clark and Kjelgren (1989) insist that pruning is essential to prevent trees from becoming problematic due to excessively large canopies and to correct structural damage of trees where branches, for example, were broken.

Replacing the 15.37% missing trees identified by this study provides an opportunity to replace 8 151 trees with healthy specimens without having to identify new locations. This will not only contribute to the maintenance of the tree canopy percentage, but it provides an excellent planting opportunity to engage with the community in the process. Communities across the city can be reached, as the missing trees were found in each of the regions. This process can also be used as a community education and training opportunity to create awareness of the importance of trees in the urban environment, coupled with the importance of maintaining the trees to ensure their survival. Education and knowledge sharing create the foundation of community support programmes and will benefit the forest in the long term and should be included in tree planting strategies (Carmichael & McDonough, 2018). Community awareness, consultation and education are furthermore crucial for the prevention of vandalism (Richardson & Shackleton, 2014).

The structured literature review (Chapter 2) highlighted the importance of creating species diversity when implementing tree planting projects, as it is important for the overall survival of the urban forest (Thompson et al., 2004). A diverse but relevant tree species list needs to be created for new tree planting in the city. Identifying trees to improve the species diversity depends on research and it is recommended that a future research study be conducted to identify species suitable for the urban environment of the CoJ.

An internet search identified tree management policies from local governments (Drakenstein Municipality, City of Cape Town, Langeberg Municipality, Overstrand Municipality, Mogale City) in South Africa, mainly from the Western Cape, but also from Gauteng. As described in the Tree Management Policy of the CoJ, the policies focus on the management of city-owned trees and consist of basic guidelines for planting, replacing and general maintenance including pruning and removing trees. The Tree Management Policy of the City of Cape Town refers to creating awareness among communities of the importance of trees and selecting and protecting historically important trees. No published guidelines for tree planting in the CoJ could be found and therefore the guidelines developed through this study are the first to provide guidance and recommendations on new tree planting projects aimed at improving tree growth and survival for this city.

8.5 Conclusion

According to McConnachie and Shackleton (2010), in South Africa, tree planting programmes are not guided or informed by research programmes and take limited cognisance of the economic and social dimensions of the specific area, influencing the distribution of these trees and their subsequent management negatively. Dwyer et al. (2003) assert that each urban forest requires a custom urban forest management strategy to ensure sustainability and the realisation of the benefits associated with the urban forest. McPherson et al. (2005) and Roy et al. (2012) state that a tree planting strategy can be developed to increase the canopy cover of a city.

The focus of this part of the study was to base the development of tree planting guidelines for new tree planting in the CoJ on the research conducted during this study. A structured literature review was conducted, and the results were used to identify components to guide the development of tree planting guidance. Relevant results from this study were included to expand the guidelines, focusing them on tree planting in the CoJ.

This study provided an assessment of the trees planted during the GSTP project, indicating the species, distribution, maintenance requirements and possible risks, and formed the foundation for the tree planting guidelines. The goals of the guidelines were linked to the Tree Management Policy of JCPZ and the objectives were based on the specific focus area components of the structured literature review, supplemented by the findings of this study.

The tree planting guidelines provide principles and recommendations for tree planting in the city, aiming to not only maintain, but also improve the canopy cover percentage of the city, improve the current survival rate of new tree planting projects and develop community involvement processes. These objectives are supported by the identification of locations for tree planting, the selection of tree species, the development of tree planting, replacement and maintenance specifications and the identification of resources imperative for the success of new tree planting projects. For each of these objectives, measurable targets and time frames were included to provide actions for implementation. These tree planting guidelines provide recommendations for the implementation of the objectives and principles identified in the Tree Management Policy of JCPZ.

This tree planting guideline is original and novel, developed by this study, for the city of Johannesburg.

CHAPTER 9

CONCLUSION AND RECOMMENDATIONS

9.1 Introduction

In assessing the trees of the GSTP project, tree species and locations of existing trees were identified and the tree survival rate of the project determined. These findings were used to develop a narrative for this study, determining the carbon value of the project at the time of the study (2018) and what the value of the project could have been if all the trees that were planted were still alive. This formed the basis for the study. Growth relationship equations for some of the trees were developed and the carbon quantity and contribution of the project to climate change were quantified. The impact of site features on the growth of these trees was determined and possible reasons for growth deviations cited, which led to identifying improved choices of species and locations for future tree planting. Finally, guidelines for new tree planting projects were developed, aiming to improve the survival rate of future tree planting projects and optimise the value added to the urban forest over an extended period.

9.2 Greening Soweto Tree Planting project

The study set out to assess the trees planted during the GSTP project and determine whether the intended outcomes of the project had materialised. The analysis involved scrutinising the verified tree register provided by JCPZ, and the lack of information in this register pointed to the need for a comprehensive tree inventory. This study provided a format for such an inventory which can be customised for use in local governments across South Africa. The field survey identified that trees were not planted only in Soweto, as the name of the project implies, but across the City of Johannesburg and mainly in previously disadvantaged townships. Trees were planted mainly in streets and in parks, confirming one of the aims of the project, namely to transform the previously disadvantaged regions of the city by beautifying streets and developing parks that the city residents could be proud of. The survey also identified the tree species and different categories of missing trees.

Of the 13 indigenous species found in this study, 90.7% of the trees consisted of four species only, resulting in limited tree species diversity across the project. Low species diversity increases the risk of catastrophic losses due to species-specific harmful agents, necessitating a focused attempt to increase this diversity. The survey identified 15.37% of the existing trees as missing and categorised them as dead, absent, coppice growth only, dead stumps and stumps with coppice growth. By not replacing these trees, a negative aesthetic impression of the tree planting project is created. Definitive reasons for dead and absent trees and dead stumps were not identified. The species diversity and missing tree findings were used in part to inform the tree planting guidelines developed in this study.

The field survey revealed that more than the target number of trees were planted by the due date, but only 43.46% (n = 89 644) of these trees could be verified as existing in 2018. This can partly be attributed to incomplete information on the tree register, but more so by a high mortality. The high mortality reduced the overall success of the project, challenging the aim of the project which was to ensure that the benefits of the 2010 FIFA World Cup in South Africa did in fact extend beyond the event. The low survival rate is in contrast with the aim of JCPZ to realise a 95% survival of new tree plantings and implies that there were shortcomings in the management and implementation of the project and subsequent maintenance of the trees. It is suggested that in future, tree planting targets be more conservative, ensuring that funds are provided not only for tree planting, but for continued maintenance with the aim to accomplish a 95% or a suggested 100% survival rate. A framework for the involvement of the community in future tree planting and maintenance should be developed and implemented to raise awareness and involve the residents in decisions such as the type of species and locations for tree planting projects. Involving the community in tree planting and maintenance decisions will address accountability and stewardship.

The analysis of the tree planting project set the scene for the research to follow, as the findings of the analysis led to questions regarding the carbon quantity and value that the project is currently adding to the urban forest, the value it could have added if all the trees that were planted were still alive and the sequestered value of the carbon after 30 years of growth. Carbon calculations depend on the availability of species-specific growth equations and an attempt to develop growth equations for the indigenous trees in the CoJ was made. The lack of guidelines for tree planting and maintenance provided the opportunity to develop guidelines to improve current tree planting practices for new tree planting in the city. The development of such guidelines depended on data to inform the choice of planting location and tree species, as well as tree planting and maintenance specifications to improve the survival rate of trees. Therefore, the impact of land use, land cover and external site factors on the growth of trees in a city environment was determined.

This is the first time that an assessment of the street and park trees of the GSTP project or any other tree planting project of the CoJ has been conducted.

9.3 Growth parameters and allometry

The aim to determine interactions between growth parameters of the trees of the GSTP project was realised. VolCalc was used for these calculations and new allometric equations were developed for one of the species in the study.

VolCalc was successfully used to provide data for the interaction of the growth parameters for the species of this study. It requires only a digital camera and object of known size, and it is a swift and rigorous method for collecting tree dimension parameter data. However, the software program does not calculate DGL, CGL, DBH and CBH, which will still require either a tape measure or calliper to measure.

This study revealed that there are no differences in growth of the trees between the different regions of the city, indicating that future tree planting projects can be implemented in all the regions of the city as similar growth can be expected across all regions. This study confirmed that trees found in parks have higher growth rates than trees found in streets, pointing to the importance of planting trees in parks as a first option. *C. africana* trees should rather be planted on sidewalks than on medians, *S. lancea* trees should preferably be planted on medians and *C. erythrophyllum* may be planted on sidewalks or medians, as they would grow well in both locations. *Olea europaea* subsp. *africana* trees should only be planted in parks as they do not grow well on sidewalks or on medians. By planting these trees in these locations, they are afforded the best opportunity for survival and growth. This knowledge is new and should be used to guide future tree planting decisions to improve the success rate of these trees and tree planting projects, highlighting the importance of this research. Studies describing the differences in the sizes of trees planted on medians and sidewalks in streets and parks in the CoJ could not be found, revealing this as new information produced by this study.

This study established a strong relationship between the growth parameters CGL and CBH, indicating that CGL can be used to predict the CBH of indigenous trees and both measurements can be used to develop regression equations for African savannah trees. This is new information; previously Tietema (1993, citing Dayton, 1978) and Stoffberg (2006, citing Shackleton, 1997) stated that to develop regression equations for African savannah trees, the use of CBH is not appropriate.

The results from this study produced very weak to moderate correlations between both CGL, CBH and growth parameters: tree height (m), height of maximum canopy diameter (m), height at first leaf (m), maximum canopy diameter (m), stem diameter at first leaf (m) and volume (m^3). The growth curves developed by this study did not produce the typical logarithmic trendline shape. Possible explanations for the weak correlations and low R^2 values of the results may be the substantial variation in tree height relative to tree age and the lack of mature trees in the study. McPherson et al. (2016) state that the prediction of any growth/age-related parameters depends on correct tree age data, as it is the starting point of allometric equations. Both McPherson et al. (2016) and Semenzato et al. (2011) confirm that it is difficult to develop growth equations to predict tree height and other variables for young and smaller trees from DBH. The growth parameter data for this study confirmed that the trees were still young (between 11 and 16 years) and indicated that the youngest trees were not the shortest and the oldest trees were not the tallest. The variation in the growth of the trees in this study may be attributed to different sizes when planted, site, environmental or soil conditions and varying maintenance operations, but may also be attributed to errors that might have occurred when the planting date information on the tree register was captured.

Even though allometric equations could not be developed using the fieldwork data only, the VolCalc data can be used to inform tree planting policies or strategies and best management practices for the selection, planting and maintenance of trees. The mean maximum canopy diameter growth parameter for each of the species can be used to indicate the minimum planting distances of the trees; the height at first leaf data can be used to indicate pruning needs for crown lifting to a specified height that would accommodate pedestrian movement next to street trees; tree height can be used to indicate pruning needs close to overhead cables and structural elements.

New growth rate equations were developed for *O. europaea* subsp. *africana* and *S. lancea* by combining the data from the cities of Tshwane and Johannesburg. These equations are applicable to Gauteng, South Africa. They could be used for predicting the physical dimensions of these species to assist in planning future tree planting by indicating how far apart the trees should be spaced in parks and on medians or to determine the distance these trees should be planted from structures such as buildings, bridges or street lights. A literature search revealed no information related to the growth of *O. europaea subsp. africana* in Gauteng.

9.4 Carbon stock value and carbon sequestration

The Kyoto Protocol recognises carbon sequestration and storage as a valid means to mitigate climate change and depends on the quantification of the carbon sequestered by vegetation, soils and oceans. The objective of this part of the study was to complete a carbon assessment and determine the value of the GSTP project, which included the determination of standing carbon stocks, an estimation of the potential projected carbon sequestered over a period of 30 years and a determination of the monetary value of the trees of the project. This study determined that the GSTP project contributed 30 390.11 tCO_2 of standing carbon stocks valued at R3 646 812,87 or US$303,901.07 in 2017 and could potentially contribute 387 170.93 tCO_2 of sequestered carbon stocks valued at R46 460 511,82 or US$3,871,709.32 in 2031 as climate change mitigation. In South Africa, carbon stocks and carbon sequestration studies have been conducted for the city of Tshwane using *C. erythrophyllum, S. lancea* and *S. pendulina* (Stoffberg et al., 2006, 2010). This current study produced carbon stocks and carbon sequestration information for the GSTP project using not only *C. erythrophyllum, S. lancea* and *S. pendulina,* but also 10 other indigenous species (*A. falcatus, C. africana*, *H. caffrum, K. africana, O. europaea* L. subsp*. africana*, *P. henkelii*, *P. latifolius* , *S. brachypetala*, *S. galpinii*, *V. karroo, V. sieberiana* var. *woodii*). This is the first time that these species have been used in an urban context in South Africa to quantify carbon sequestration. A literature search did not produce any study in urban environments in Africa using these species. This is the first time that standing carbon stocks have been quantified, the potential projected carbon sequestered over a period of 30 years has been estimated and the monetary value of all the trees of the project has been determined. It is also the first time that a carbon study for the CoJ across regions has been conducted, and the conclusion can be made that this study produced new and novel information.

The quantity of carbon sequestration is influenced by the size and number of the individual trees in the study. Therefore, the species with the most trees (*C. africana*) and the widest circumferences (*V. sieberiana* var*. woodii*), and the region (Region C) with the most trees in the study contributed the most to the standing carbon stocks. The sidewalk trees had accumulated most of the standing carbon stocks and the median trees the least.

This study also aimed to estimate the potential projected carbon sequestration over a period of 30 years for different scenarios, depending on the number of trees anticipated to be growing healthily and normally by 2031. It is estimated that in a scenario where the target number (n = 200 000) of the trees were still alive by 2031, the GSTP project could have sequestered a potential quantity of 375 407.54 tCO_2 valued at R45 048 904,40 or US$3,754,075.37 as a contribution to climate change mitigation. The scenario in which it was estimated that only 89 644 trees were existing by 2031 revealed a potential quantity of 168 265.17 tCO_2 sequestration valued at R20 191 819,93 or US$1,682,651.66, resulting in a loss of 56.54% in the value of the project if compared to the value if all the trees that were originally planted were growing and healthy in 2031. The worst-case scenario was estimated to be 44 887 trees, which was determined by using the trees with addresses (n = 53 038) as a basis and removing the missing (n = 8 151) trees. The value of this scenario (R10 110 550,86 or US$842,545.90) is 22.44% of the value of the target number of trees (n = 200 000) of the GSTP project, indicating a loss of 77.56% in the value of the project. Therefore, higher survival rates of tree planting projects will result in higher carbon sequestration over time and higher carbon sequestration levels in relation to climate change.

As carbon trading projects could present an opportunity to local governments to become active in the offset markets, this study provides valuable information for future carbon trading opportunities and shows that carbon sequestration value increases as the number of trees increases. If the target of the city to aim for a 95% survival rate were reached and 190 000 trees are estimated to be alive in 2031, this would have a potential quantity of 356 637.16 tCO_2 valued at R42 796 459,18 or US$3,566,371.60. When the latter scenario is related to the scenario where 43.46% of the trees are estimated to be alive, the difference in the estimated value is R22 604639,25 or US$1,883,719.94. Consequently, the lack of appropriate maintenance and possible incorrect choices of tree species and locations or the impact of environmental and site conditions have resulted in an estimated loss of R22 604 639,25 or US$1,883,719.94. This is the first study to estimate the potential projected carbon sequestration for a specific tree planting project consisting of indigenous trees in the City of Johannesburg in South Africa.

9.5 The impact of land use, land cover and other site features on tree growth

The aim of this part of the study was to determine the distribution of the trees in the study across land use, land cover and other site features or external factors, to establish whether these factors impact on the growth of trees and to identify aspects that could impact on future tree planting and maintenance strategies.

9.5.1 Land use

As discussed above, approximately two-thirds of the trees were planted as street trees on sidewalks (n = 1 379) and medians (n = 319) and one-third in parks (n = 814). Additionally, this part of the study showed that most of these street and park trees were found in formal residential land use areas in maintained lawn land cover. These findings confirm previous research that park and residential land uses potentially provide the best planting locations in a city, affecting growth of the canopy cover upon maturity and the percentage total canopy cover (Nowak et al., 1996; Dwyer et al., 2000; McPherson et al., 2011; Mincey et al., 2013). Hence the importance of ensuring that the trees that are planted survive to maturity so that they can contribute to the canopy cover of the city. The findings of the missing trees were that the vacant land and informal residential land uses had the most missing trees. When future tree plantings are planned on these land use areas, actions are required to improve the survival rate of these trees.

9.5.2 Land cover

The maintained grass, bare soil and paving land covers had a positive impact on the growth of trees. The positive impact of bare soil and paving are in contrast to international research which found that trees planted in paving have increased mortality rates (Elmes et al., 2018).

9.5.3 Maintenance needs

The maintenance needs of the trees in the study were identified. Trees that did not require any maintenance were on average larger than those requiring some form of maintenance, confirming that the growth of trees is negatively affected when some form of maintenance is required.

The need for pruning, specifically the removal of coppice, was established as the primary maintenance requirement. Very little pest and disease presence was found but may in future become problematic if not managed carefully and kept under control by applying IPM practices (Clark & Kjelgren, 1989). Vogt, Watkins et al. (2015) and Nowak et al. (1990) confirm the importance of maintenance to ensure the success of tree planting projects.

All the species in the study required some form of pruning, except for the *V. karroo* trees (n = 3). The tree species mostly affected by the need to remove coppice growth was *C. erythrophyllum* – 46.3% of these trees required this maintenance activity. Pruning is required to remove coppice growth before it becomes too vigorous, changing the tree structure into a shrub shape, thereby losing the benefits produced by trees. Pruning was also required to repair broken branches, prevent further damage to the tree and structurally shape the tree into suitable forms fitting urban conditions such as traffic, fence lines and overhead structures. Even though most of the trees were found in maintained land use areas, the absence of pruning was evident, indicating the need to implement regular structural and preventative pruning operations. Other researchers confirm that pruning young trees is important and essential for successful tree establishment and will reduce pruning needs of mature trees (Nowak, Stevens, Sisinni & Luley, 2002).

9.5.4 Land use, land cover and maintenance

Where the maintained grass land cover was found in conjunction with formal residential and park land use areas, a positive connection was found between land use, land cover and maintenance on the growth of the trees. The land uses “vacant land” and “informal residential” are not traditionally maintained, providing a plausible reason for the negative impact of these areas on the growth of the trees.

The positive impact of the bare soil and paving land covers was investigated and it was found that the trees in bare soil were planted during the first year of the project. Some of them were in park land uses surrounded by maintained lawn. The trees in the paving land cover were found at the Rea Vaya bus stations where irrigation and other maintenance are also provided. The impact of maintenance on the growth of trees is emphasised and is integral to the survival and growth of trees. Where trees were found in maintained land use areas, they were larger than trees found in unmaintained areas.

9.5.5 Human influence

Except for pedestrian traffic, the other human influence categories impacting the growth of trees were all maintenance related, reinforcing the importance of maintenance. Contrary to the findings of a research study that pedestrian traffic may negatively impact tree growth (Lu et al., 2010), this study showed that trees with wide mean circumferences were not negatively impacted by pedestrian traffic. Several missing trees were identified in parks, formal residential and maintained open spaces where traditionally high levels of pedestrians are found. This shows that even though pedestrian traffic does not negatively impact the growth of the trees, it may result in vandalism such as the breaking and damaging of trees, resulting in coppice growth, dead stumps or even dead trees.

9.5.6 Pests and diseases

Very few pests and diseases were found but may become problematic if not managed carefully and kept under control (as confirmed by Clark and Kjelgren (1989), Vogt, Watkins et al. (2015) and Nowak et al. (1990)). The growth of *O. europaea* subsp. *africana* was negatively impacted by the presence of pests and diseases, meaning that if this species is used in future tree planting in the city in terms of where or when it is planted, attention must be paid to pest management of the species. Even though no presence of the polyphagous shot hole borer pest and its fungal symbiont was identified in this study, a scouting programme should be implemented to detect evidence of this pest to prevent catastrophic results in future, as evidence of this pest has been found in the established urban forest of the CoJ (Mokoena, 2020).

9.5.7 Conflict

The only categories of conflict impacting the trees in this study were overhead structures and roads. This is currently not a major concern as these trees are still young, but when they are mature these conflicts may impact their growth negatively and the trees may have a negative impact on the structures themselves. When large trees of substantial height are found directly under and in very close proximity to overhead structures such as electrical conductors, the trees will interfere with the overhead structures and may cause a flash-over. Similarly, large tree species will create conflict with roads and the kerbs next to roads, if planted too close to the edge of the road. Planting large-growing trees under any overhead structures and too close to the road should be avoided and attention should be paid to choosing small-growing trees that will not cause conflict with these structures when mature in size.

9.5.8 Impact on species

Of the four species with the most trees in the study, the growth of *C. africana* and *S. lancea* were the least impacted by maintenance requirements, human influences, pests and diseases and conflict. They were identified as the best adapted species for use in urban environments in the CoJ and should receive preference when trees are selected for new tree plantings in areas where other tree species struggle to grow optimally. This statement does not imply that only these trees should be planted, however, as doing so would negatively impact the species diversity of the urban forest.

The coppice growth concern with *C. erythrophyllum* and the pests and disease occurrence in *O. europaea* subsp. *africana* require resolving before these trees can be ideal for use in the CoJ. This may be achieved by the implementation of a pruning and a pest and disease programme for the city. Once the coppice growth of *C. erythrophyllum* is managed, this species can also be added to the list of suitable trees for the city as this species had the least pests and diseases of all the species in the city. The land use and land cover placement of *O. europaea* subsp. *africana* need consideration to prevent inferior performance and pest and disease infestation. Rather than not using these trees in the city environment, the pests and diseases must be managed to prevent inferior growth performance. This is new information that can be used to guide the species choice and placement of future tree plantings, to replace the distressed, non-performing trees, to implement a planned maintenance programme and manage the poor performance back to health and to ensure improved survival of trees.

9.5.9 Impact on regions

There was no statistical difference in tree growth between the different regions of the city. There was no statistical proof that trees grow better or worse in one region compared to another, leading to an expectation that in future all trees in the city will have a similar chance of survival and growth.

The intention of this part of the study was to identify aspects that could influence future planting strategies and provide information to city managers to refine their planting practices and policies. Studies that determined the effect of land use, land cover and other external factors on the growth of indigenous South African trees, in particular *C. africana, C. erythrophyllum, O. europaea* subsp. *africana* and *S. lancea* tree species, could not be found. This study is the first to describe the effect of land use, land cover and the different external factors on the growth of indigenous South African trees and to identify aspects that could influence future planting strategies.

9.6 Tree planting guidelines

The final part of the research aimed to develop guidelines for new tree planting projects to improve the survival rate of planted trees and optimise the value added to the urban forest over an extended period. Findings from the structured literature review were combined with recommendations developed by this study to create guidelines for new tree planting by the CoJ linked to the Tree Management Policy of JCPZ. Research shows that tree planting programmes in South Africa are not based on research (McConnachie & Shackleton, 2010), which makes these guidelines the first custom guidelines for the CoJ to be informed by research. These tree planting guidelines are new knowledge developed by this study for the CoJ and may be used by other local government parks departments to guide tree planting in their respective councils.

The aim of the tree planting guidelines was to develop principles informing new tree planting projects and prevent a recurrence of the tree survival results of the GSTP project and rather secure a 100% survival rate in future. The structured literature review identified components for the development of these guidelines and these were augmented by relevant results from this study. These guidelines are practical recommendations of how the findings from this study can be used by JCPZ to change the practices applied during the GSTP project and are provided as supplementary to the current Tree Management Policy of the CoJ to provide recommendations for the implementation of the goals and objectives of the policy. Where possible, the information in the guidelines is supported by literature or the findings of this study.

The principles for guiding tree planting in the city were based on the Tree Management Policy of JCPZ and comprise a target of improving the canopy cover of the previously disadvantaged regions of the city by 10% per annum, maintaining the canopy cover in the historically advantaged northern suburbs, aiming for a 100% survival rate of new tree planting projects, developing community engagement structures aimed at involving the local community in new tree planting projects before another tree planting project is attempted and introducing performance measurements.

The guidelines and recommendations in this current study link to the principles mentioned above and the steps required to implement new tree planting projects according to the acknowledged principles were explained. The first step entails identifying locations for tree planting based on land use and land cover types to afford the trees the best opportunity for growth and survival. The second step is selecting the best tree species in the planning of new tree planting projects, followed by the third step which entails developing and implementing tree planting and replacement specifications. Step 4 is the development of maintenance specifications, plans and practices. The last step is to identify dedicated resources, including human resources, equipment and funding, imperative for the success of new tree planting projects.

When funding is made available and there is political support, a tree planting project can be successful. The GSTP project is a good example. The target to plant 200 000 trees was reached and most of the trees were planted in previously disadvantaged regions such as Soweto, improving the canopy cover percentage of the southern disadvantaged regions of the city. However, the low survival rate of the trees planted during this project indicate that not all the targets of the project were reached, and a 95% survival rate was not achieved as only 43.46% (n = 896 44) of the 206 267 trees on the tree register had survived eight years after the project was completed, in 2018. Therefore, it was important to identify priorities for the implementation of the tree planting guidelines to ensure that the objectives are realised during the next tree planting project.

Priorities for the implementation of tree planting guidelines were determined based on the structured literature review and the findings of this study. The first priority for the implementation of these guidelines is to develop and implement community engagement structures so that the community can have an input in the selection and location of tree species and the planting, care and maintenance of these trees, prior to the initiation of the tree planting project. This priority includes the development of stewardship programmes responsible for tree care and maintenance. The replacement of the missing trees was identified by this study as a priority as it provides an immediate opportunity to improve the number of trees in the city, without having to identify new planting locations. This process may be used as the first community engagement opportunity to provide education and training and create awareness of the importance of trees and their maintenance in the urban environment. Richardson and Shackleton (2014) state that community awareness, consultation and education are crucial for the prevention of vandalism, highlighting the importance of involving the community in this priority.

The development and implementation of tree maintenance guidelines were also identified as a priority to proactively maintain new tree plantings during the establishment phase of the projects; this is crucial for the survival and growth of newly planted trees. The removal or pruning of coppice growth was highlighted as the most important maintenance requirement.

The JCPZ Tree Management Policy does not refer to coppice growth, and coppice growth as a concern regarding urban trees could not be verified by literature. This is thus new information provided by this study.

The development of a list of tree species aimed at improving the species diversity in the urban forest is the last priority of these guidelines. This list is dependent on research and it is recommended that a future research study be conducted to identify species best suited for the urban environment of the CoJ.

9.7 Suggestions for future research

This study identified further study opportunities with regard to the GSTP project and the urban forest and these are summarised below:

- Research should be conducted to determine the reasons for the missing trees so that a plan can be formulated to counteract the further loss of these trees.
- Research is suggested to identify the causes of vandalism in the CoJ in order to create prevention measures for future tree planting.
- The VolCalc software program does not calculate DGL, CGL, DBH and CBH. It is recommended that these variables be added to the software program.
- Growth rate equations should be developed for the trees in the urban forest of the CoJ by utilising the data from this study and supplementing it with data on large, substantially older and established trees.
- The effect of soil and environmental conditions (precipitation, wind and pollution) on the growth parameters of these trees in the different regional locations should be determined to identify their influence on the survival rates of these trees.
- A research study should be conducted to identify more indigenous species other than the 13 indigenous species used in this study, to improve the species diversity of the urban forest.
- A research study should be conducted to identify exotic species that are suited for use in the city, to improve the species diversity of the urban forest.
- The optimum number for a large tree planting project to guarantee a 100% survival rate of the project should be determined.
- The views of the different communities in the different regions of the city about the GSTP project should be investigated to allow for future planning and involvement oportunities to improve the survival of trees.

- Research is required to identify implementation of stewardship programmes in the different regions of the city to assist with the maintenance of these trees.
- Further investigation is required to determine the impact of mulch on tree establishment prior to including it in a tree planting specification.
- The value of other benefits (economic, environmental, social and health) and ecosystem services (e.g. air pollution filtration, mitigating the urban-heat-island, storm water management) of the trees of the GSTP project and of the urban forest of the CoJ could be determined.
- A cost-benefit analysis of the trees planted during the GSTP project can be conducted to identify the benefits derived from spending funds on the urban forest.
- Research is suggested to identify suitable systems (such as i-Tree) that can be used in the CoJ to complete a city-wide tree inventory.

Previously, there was limited data available on trees and the urban forest in the CoJ. This study contributed to improve this data and the existing knowledge of the urban forest of the CoJ. Together with the recommendations this study may assist JCPZ in future decisions regarding urban forestry and tree planting in the city.

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